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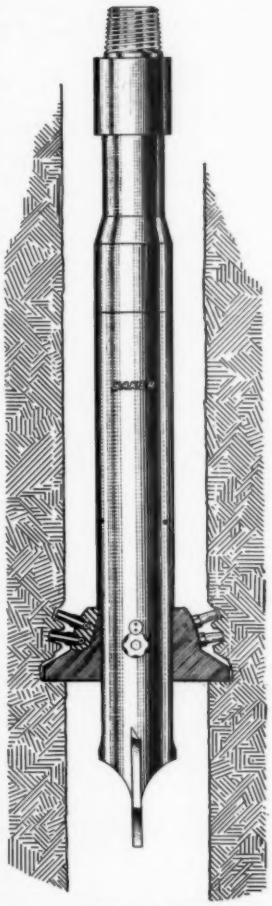

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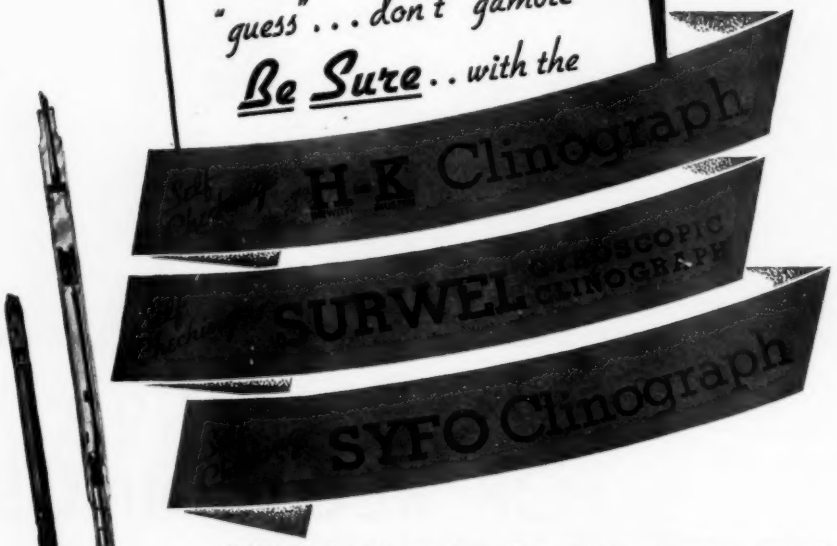

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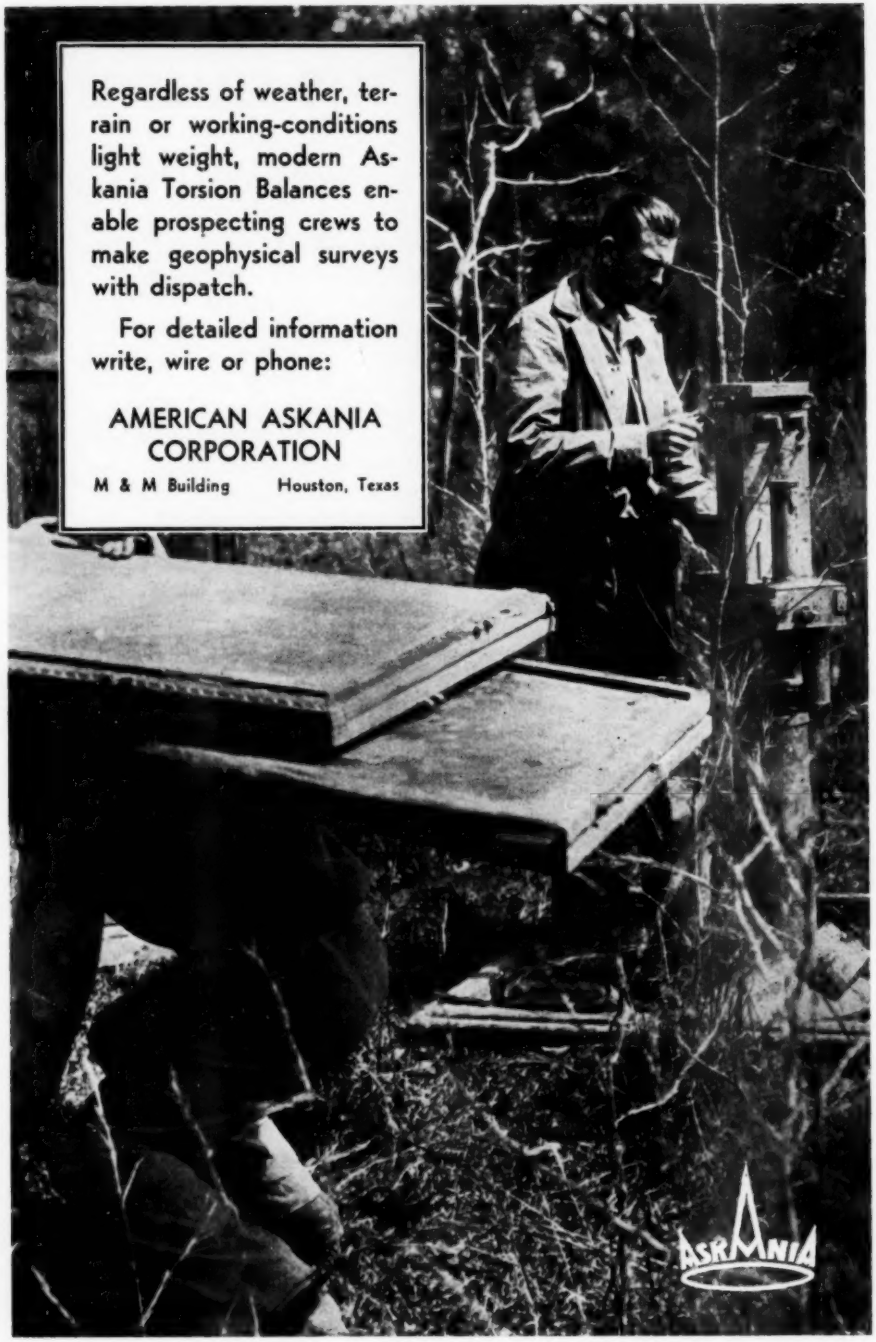
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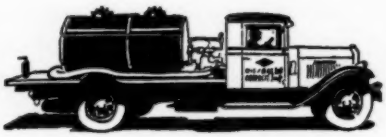

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BULLETIN
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AUGUST, 1936

ESTIMATION OF PROBABLE VALUE OF WILDCAT LAND[1]

E. L. ICKES[2]
Los Angeles, California

ABSTRACT

An attempt is made to calculate the probable net profit per acre of a piece of undeveloped wildcat acreage, using the theory of probabilities. Formulae for the purpose are derived and some examples worked out. The answers obtained depend wholly on the estimator's selection of the various probabilities used in the formulae.

INTRODUCTION

This paper is written mainly for the attention of the oil geologist, who, like the writer, has been called upon at times to give an opinion concerning the price to be paid for undeveloped or wildcat land. An attempt is made here to apply the elementary principles of the theory of probabilities in estimating the value of this acreage. The writer lays no claim to being especially proficient in this theory and he may be charged with taking liberties with its application by those skilled in its use; even so, the attempt would be justified if it served to bring forth further discussion on the subject.

The theory is used extensively in the insurance business in estimating risks, in scientific betting on games, and in statistical work in some of the natural sciences and engineering. The theory is more accurate in its application when a large number of cases is being considered. A large oil company usually acquires a considerable number of leases which are continually added to or quit-claimed as test wells are drilled or as further information is obtained to enable a revaluation of property. Hence, in the case of a company with numerous leases, it may be

[1] Manuscript received, April 21, 1936.

[2] Geologist, Western Gulf Oil Company.

expected that the probability theory might be applied usefully to the question of what price should be paid for undeveloped acreage. It might be argued that it is not always possible to secure land at its theoretical price; nevertheless a scientific guess of its worth, such as is afforded by the application of the principles of the probability theory, may be of considerable value to the operator.

Very little discussion of the elements of the theory itself is given in this paper. The only paper that has come to the writer's attention, which attempts to apply the theory to the oil business, is one by Hayward[3] which goes into the fundamentals and should be consulted. Again, if the reader desires further information, he is referred to the chapter on probability in Sokolnikoff's book[4] which explains the theory in considerable detail.

The intelligent application of the theory of probability to leasing problems requires a great deal of statistical information and geological knowledge. The greater this information is, the better the results obtained in the long run should be, especially when dealing with a large number of leases.

SOME STATISTICS

A study of California records shows that, in the period from 1914 to 1932, 696 wildcats were drilled by the major companies resulting in the discovery of 25 oil fields, a ratio of 1 to 28; that is, the probability or chance for a successful average wildcat well, presumably based on sound geological advice, is, when drilled by a major company in California, expressed as $p=\frac{1}{28}$.

Hayward[5] gives the ratio $\frac{1}{74}$ as the probability for a successful average wildcat in the United States, based on records for the period from 1859 to 1928.

In the theory of probabilities, the most probable number of successes is $\epsilon=pn$, where p is the number of successes divided by the total number of wildcats that have been drilled, and n the number of wildcats to be drilled. The probability of ϵ is

$$p_\epsilon=\frac{1}{\sqrt{2\pi npq}} \text{ where } q=1-p.$$

Thus, in California, where 696 wildcats yielded 25 successes,

[3] John T. Hayward, "Probabilities and Wildcats Tested Through Mathematical Manipulation," *Oil and Gas Journ.* (November 15, 1934), pp. 129–31.

[4] I. S. and E. S. Sokolnikoff, *Higher Mathematics for Engineers and Physicists*, McGraw-Hill Book Company, New York, 1st ed. (1934), pp. 365–94.

[5] John T. Hayward, *op. cit.*

$$p=\frac{25}{696}=\frac{1}{28} \text{ and } q=\frac{27}{28}.$$

Then the probability of getting one success in the next 28 similar wildcats is

$$p_e=\frac{1}{\sqrt{6.28\times 28\times\frac{1}{28}\times\frac{27}{28}}}=.405 \text{ or } \frac{2}{5}.$$

Again, if 10 wildcats have yielded one successful well, then the probability of getting one success in the next 10 of the same class drilled is found to be $p_e=.42$ or $\frac{21}{50}$.

Owing to the large element of uncertainty present in estimating the various probabilities in this paper, the probability of p_e is disregarded, and it is herein assumed that if 1 well in 28 was a success, then there will be one success in the next 28 drilled, and so on.

PAYMENTS

The argument of this paper is that the price paid for acreage should be based on the probable net profits per acre derived from the oil obtained. The value of the theoretical probable net profits is calculated herein, and this figure then affords a measuring rod to enable the operator to estimate either what price to pay as a down payment, or what rentals are reasonable to hold the land until such time as a well is drilled or until new information develops which permits a revaluation of the property.

It is assumed that the purchasing company is willing to pay rentals on the property, equivalent to ordinary interest rates applied to the net profits, until such a time as the ground is proved or disproved and the rentals cease. If land is obtained in this way, a large company may hold a parcel indefinitely as long as the evaluation of the probable net profits is not changed, since the company is merely paying interest rates on a sum estimated to be concealed in the ground as oil.

NET PROFITS FOR A SURE-SHOT

Sure-shot acreage is proved acreage or acreage certain to produce oil; in other words, its probability of success is unity or 1 in 1.

For any acre in this class of land let

q = cumulative production per acre in time t,

Q = total or ultimate yield per acre during the life of the lease,

$\frac{dq}{dt}=F(t)$, the production rate at time t, such as barrels per day,

m = operating costs and royalty on a barrel of oil at time t,

n = selling price of oil at time t,

$r = n - m$, profit per barrel at time t, or operating profit.

The oil produced by an acre in a short interval of time dt is $dq = F(t)dt$.

The profit on this amount of oil at time t is $rdq = (n-m)F(t)dt$.

The total operating profit obtained per acre from the beginning of operations until time t is, therefore,

$$R = \int_0^t rdq = \int_0^t rF(t)dt,$$

which is a general equation applicable to all conditions of variation of price, operating costs, production rates, and the like; this can be evaluated provided these variables are determinable in advance.

If r, the difference between the price of oil, and operating costs and royalty, is assumed to be the same or averaged, during the production period, then the foregoing integral expression is easily reduced to the equation $R_t = rq$. In this paper r is assumed of necessity to be constant or an average during the period of production. Therefore, at the end of the production period the total operating profit is $R = rQ$.

From the figure R, we must deduct the geological, geophysical, and drilling costs per acre.

Let N be net profits per acre for a sure-shot, then

$$N = rQ - C \qquad \text{(Equation 1)}$$

where C is exploration and drilling costs per acre.

In cases where statistical and other information is so good that the future price of oil, operating costs, decline curve and length of time of operations can be obtained with some accuracy, the present worth of the future profits can be taken into account. Also where the life of a field is extended by proration, the future profits might be calculated as to present worth. In this paper, however, the various factors influenced by future events are considered too uncertain to permit correcting for present worth.

CLASSES OF WILDCAT ACREAGE

In this paper wildcat or undeveloped land is divided into two classes.

Class I.—Acreage situated on a known structure or trap which has been definitely mapped by geological or geophysical means.

Class II.—Acreage in an area where a trap is suspected to exist, but whose detection depends on further work or information. At the

time the acreage is purchased, the location of the structure is unknown and its presence as yet not proved.

CLASS I ACREAGE

Known and mappable structures or traps are classified herein as sure-shot, excellent-shot, good-shot, fair-shot, average-shot, poor-shot, and very poor-shot. These classifications may be, perhaps, in too great detail; the classification of a certain structure depends on the geologist's opinion, which is founded necessarily on geological and statistical knowledge. One geologist may classify a certain structure as a good-shot, while another might classify it as fair-shot or even a poor-shot. This opinion is a personal equation.

In seeking a formula which will give numerical values to the probabilities of success for the various shots just mentioned, we must use one which satisfies the requirement of making the probability unity for a sure-shot, and a small value for a long-shot. An equation which meets these requirements is

$$p = e^{-ax} \qquad \text{(Equation 2)}$$

where p is the probability of success for a structure of rating x,
a is a constant,
$e = 2.7183$, the base of natural logarithms.

Equation 2 shows that when $x = 0$ then $p = 1$ and we have a sure-shot. If x measures the longness of the shot, then the equation shows that the probability p is small for long shots. For convenience, making $x = 1$ for an average shot, $\frac{1}{24}$ to $\frac{1}{28}$, we get the following probabilities for the different shots.

TABLE I

Class of Structure	*Probability of Success, p*
Sure-shot	Unity or 1
Excellent-shot	$\frac{9}{10}$ to $\frac{1}{3}$
Good-shot	$\frac{1}{3}$ to $\frac{1}{9}$
Fair-shot	$\frac{1}{9}$ to $\frac{1}{24}$
Average-shot	$\frac{1}{24}$ to $\frac{1}{28}$
Poor-shot	$\frac{1}{28}$ to $\frac{1}{80}$
Very poor-shot	$\frac{1}{80}$ to $\frac{1}{250}$

It now remains to evaluate the chance of success of an acre situated on one of the foregoing prospects. Here it is considered that the acre may be on the "best" structural position, or it may be in a

"good," "fair," or "poor" structural location. We now need a formula that satisfies the requirements that for the best structural location the probability is p of equation 2, and that the probability decreases as the riskiness of the structural position increases. An equation which satisfies these requirements is

$$P = pe^{-bz} \qquad \text{(Equation 3)}$$

where P is the probability of success for an acre on the structure,
p is the probability of success for the best location, where p is determined by equation 2 or Table I,
z is the structural position; $z = 0, 1, 2$ and 3 for the best, good, fair, and poor structural positions, respectively,
b is a constant.

To evaluate b the writer assumes that the chances of the poor acreage are 10 per cent of those of the best acreage. This makes $b = 0.7675$.

Using these results, we then find that an acre on the structure has the following probabilities.

TABLE II

Structural Location of Acre	*Probability of Success, P*
Best location	p
Good location	$\frac{p}{2}$
Fair location	$\frac{p}{5}$
Poor location	$\frac{p}{10}$

Probable net profits for Class I acreage.—The probable net profit per acre for a sure-shot is, by equation 1, $N = rQ - C$. The probable net profit for an acre lying in one of the structural positions already defined is shown in Table III.

TABLE III

Structural Location of Acre	*Probable Net Profit per Acre*
Best location	$E_1 = Ne^{-az} = pN$
Good location	$E_2 = \frac{E_1}{2}$
Fair location	$E_3 = \frac{E_1}{5}$
Poor location	$E_4 = \frac{E_1}{10}$

General equation for Class I acreage.—It can be shown now that the general equation for Class I acreage may be written

$$P = e^{-ax-bz} \qquad \text{(Equation 4)}$$

where P is the probability of success for an acre on a given structural position,
x is the longness of the shot; $x=1$ for an average shot,
z is the structural position; $z=3$ for a poor position,
a $=3.25$ and
b $=0.77$, in this paper,
e $=2.7183$.

CLASS II ACREAGE

This is land with no known traps but they are suspected to exist. Acreage of this class has a large element of uncertainty and is of less value than Class I land. The moment a structure is found on Class II acreage, the area surrounding the structure becomes Class I acreage.

For Class II acreage let

L be the area of the block under consideration,
A be the estimated area of suspected production which may exist under L,
$p_0=\frac{A}{L}$, the probability of any acre in block L being located on a pool of area A; this applies when area L is larger than area A; but in case area A exceeds area L, then p_0 is always unity and at no time greater than 1,
p be the probability that the structure, if found, will produce oil,
p_1 be the probability that a structure exists under acreage L; the more complete is the geological information, the better will be the estimate of this probability,
p_2 be the probability that a given acre in area L will be productive; $p_2=pp_1p_0$,
N be the probable net profits per acre for a sure-shot structure of this type; $N=rQ-C$ (see equation 1),
p_2N represent the expected net profits for any acre in area L.

Therefore, the equation sought is

$$E=pp_1\,p_0N \qquad \text{(Equation 5)}$$

where E equals the expected net profits per acre for any acre in area L.

Equation 5 is of general application to Class II acreage.

Trend lines and faults.—A structural trend or a fault extends toward a certain district and it is desired to ascertain the probability of it crossing a given piece of property in the district. The geologist

with his knowledge of the country determines what he considers the limits of the trend; that is, $A_1 B_1$ in Figure 1 represents the estimated limit on one side of the property and $C_1 D_1$ the limit on the opposite

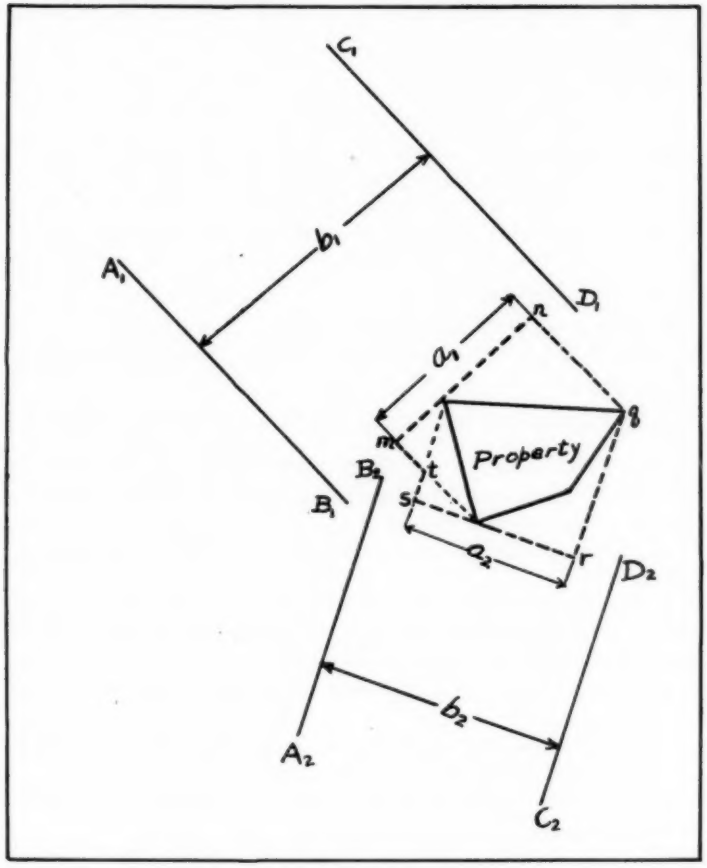

FIG. 1.—Land on probable intersection of two trends or faults.

side, the direction of the lines being that of the suspected trend. The trend can pass equally well through any point of the line b_1. Line a_1 is the projection of the width of the property on a line perpendicular to the trend. The probability that the trend or fault crosses the property is therefore $\frac{a_1}{b_1}$.

Equation 5 becomes

$$E=\frac{a_1}{b_1}(pp_0)p_1\,P_1N \qquad \text{(Equation 6)}$$

where the symbols in the parenthesis are the same as those for equation 5,

P_1 is the probability that the trend or fault continues as far as the property,

p_1 is the chance that a trap or closure exists on this trend under the property.

Two intersecting trends or faults.—Suppose two trends or faults extend toward a certain district and if they continue that far and intersect, the chances are favorable for oil accumulation. What are the chances for a given piece of property to lie on the intersection?

Let a_1 and b_1 be, respectively, the projected width of the property and distance between the limiting positions of line 1 (trend or fault),

a_2 and b_2 be the same, respectively, for line 2,

P_1 and P_2 be the probability that line 1 and line 2 extend as far as the property,

$P_0=\dfrac{\text{area of property}}{\text{area } mnqrst}$, probability that the intersection occurs on the property (Fig. 1).

Then $p_1=\dfrac{a_1}{b_1}\times\dfrac{a_2}{b_2}\times P_1P_2P_0$, the probability that a structure formed by the intersection, exists under the property.

The expected net profit per acre of the property is

$$E=p_1(pp_0N) \qquad \text{(Equation 7)}$$

where p_1 is as already given, and the remaining factors are as in equation 5.

Correction for fault accumulation.—A fault or trend is considered here as likely to cross the middle of the property as elsewhere. A closure on the trend would probably yield production on both sides of the line. In the case of a fault the conditions would be different if production is expected on one side only of the fault. Hence it seems reasonable, in case of one-sided fault accumulation on land where the area of the pool is expected to exceed the area of the property, to divide equations 6 and 7 by 2 to get the expected net profits per acre for this type of accumulation. If the area of the property is greater than that of the expected pool, this halving is not necessary.

PROBLEMS

As a means of illustrating the foregoing paragraphs, the writer is giving the following problems which have been worked out. It must be emphasized that the results are merely best estimates and their accuracy depends entirely on the values assigned to the respective probabilities.

Problem I (*Class I acreage*).—Five hundred acres are offered on an undeveloped, untested structure which has been mapped by geological methods. Of the acreage offered, 100 acres are considered to be on the best structural situation, 100 acres on good location, 100 acres on fair location, 100 acres on poor location, and 100 acres in a position considered hopeless. What is a fair rental to pay for the entire block until such a time as it is tested or otherwise proved or disproved?

The chances for a successful well are considered average—that is, $\frac{1}{28}$. If a field is proved, it is expected to yield ultimately 25,000 barrels per acre. The difference between the price of oil, and the operating cost and royalty (r) is estimated to average 50 cents per barrel during the period of production. Wells will cost $30,000 each and be placed 1 to 10 acres. Geological and geophysical costs are disregarded.

Therefore, from equation 1, $N = \$.50 \times 25{,}000 - \$3{,}000 = \$9{,}500$, the net profit per acre for a sure-shot of this type.

The probable net profit per acre for the block offered works out by using Table III.

Best location	$E_1 = pN = \frac{\$9{,}500}{28} = \$339$ per acre
Good location	$E_2 = \frac{E_1}{2} = \$169.50$ per acre
Fair location	$E_3 = \frac{E_1}{5} = \$67.80$ per acre
Poor location	$E_4 = \frac{E_1}{10} = \$33.90$ per acre
Hopeless location	Nothing per acre

As it is desired to hold this piece of land by paying rental, it is estimated that an interest rate of 5 per cent will be a fair price to pay and this amount applied against the estimated net profits per acre for each structural position is as follows.

Best location	$\$339 \times .05 = \$16.95$ per acre per year rental
Good location	$\$169.50 \times .05 = \$8.50$ per acre per year rental
Fair location	$\$67.80 \times .05 = \$3.40$ per acre per year rental
Poor location	$\$33.90 \times .05 = \$1.70$ per acre per year rental

The total annual rentals for each structural position are as follows.

Best location	100×$16.95=	$1,695
Good location	100×$ 8.50=	$ 850
Fair location	100×$ 3.40=	$ 340
Poor location	100×$ 1.70=	$ 170
		$3,055 for 500 acres.

Hence, the annual rental works out to be $3,055 ÷ 500 or $6.11 per acre for the entire 500-acre block.

Problem II (*Class I acreage*).—Suppose the owner of the 500 acres of Problem I will not lease his land unless a well is drilled in the near future and a down-payment or bonus of $50 per acre also paid. Are his terms acceptable?

The total expected net profits from the 500 acres are found by multiplying by 100 the probable net profit per acre in the preceding problem, or $33,900+16,950+6,780+3,390=$61,020.

The estimated cost of the well to be drilled is $50,000 and the bonus for 500 acres is $25,000, or a total outlay required of $75,000. As this exceeds the estimated net profits, it would be taking in the long run a long chance to pay this bonus.

To explain more fully the reasoning followed in this paper, the present example may be amplified by considering a theoretical case, where the operator is dealing with 27 other properties, all of which are 1 in 28 shots and similar to the one under discussion. As a matter of fact, a large oil company, in course of time no doubt, would be considering many similar projects and if they were all handled in the same fashion, chances for greater profits would be better if the theoretical estimates could be followed.

Of the 28 properties under consideration, one is sure to produce; the probability of getting one producer in 28 is, in the strict sense, as previously explained, $\frac{1}{28}$, but in this paper this probability is made unity owing to the large element of uncertainty present in estimating the various probabilities. Of the 28 wildcats drilled, costing $50,000 each, 27 would be dry holes and one a successful well. The cost of drilling the 27 dry holes would be $1,350,000. The field discovered is estimated to yield 28×$61,020 or $1,710,000 in net profits (this might be considered the minimum amount) which exceeds by fair margin the cost of wildcatting. If, however, a bonus of $25,000 is required on each block, the total bonus paid will be $700,000; the sum of the bonus and the cost of the wildcatting is, therefore, $2,050,000 which is greater than the reasonably expected net profits; in the long run, in handling a number of leases of this character, the operator would be more apt to lose money if he paid the bonus.

The maximum net profits to be expected from 400 of the 500 acres would be $9,500×400 or $3,800,000, but this assumes that the entire 400 acres of productive territory will yield 25,000 barrels per acre. In the preceding reasoning it is assumed that only the best acreage will produce this amount of oil. The operator must decide on which figure he is willing to bet.

Problem III (*Class II acreage*).—A quarter-section is offered in an area of concealed geology where a closed structure has an excellent chance to be productive. Geophysical work by other companies has been done and some have taken acreage in the district, but the geophysical results are rumored to be inconclusive. What is a reasonable price for this acreage?

Geological information indicates that a pool in this area might produce 25,000 barrels per acre and drilling costs might be $3,500 per acre. Operating profits (r) during the life of the lease are estimated to be 50 cents per barrel.

By equation 1, $N=\$.50\times 25{,}000-\$3{,}500$ or $9,000 the estimated net profits for a sure-shot of this type.

By equation 5, $E=pp_1p_0N$

where $p=\frac{4}{5}$, estimated value, excellent shot,

$p_1=\frac{1}{10}$; this is merely a guess on the part of the estimator and is based entirely on his intuition and knowledge of the district,

$p_0=1$, since pools in this area are expected to be much larger than 160 acres.

Hence $E=\frac{4}{5}\times\frac{1}{10}\times 1\times\$9{,}000=\$720$, the expected net profits per acre for the 160-acre tract. To hold this block, the fair rental is estimated to be 5 per cent of $720 or $36 per acre per year.

Problem IV (*Class II acreage*).—A 10,000-acre ranch in an area of concealed geology is offered for lease. Geological deductions suggest there is a 1 in 5 chance of a structure being present and if this structure is located, its chances of being productive are considered to be fair, 1 in 10, and the probable producing area is estimated to be 1,000 acres with an ultimate recovery of 50,000 barrels per acre. The operating profit (r) is expected to average 30 cents throughout the producing period and the drilling and exploratory costs are expected to be $2,500 per acre.

Applying equation 1, we get $N=\$.30\times 50{,}000-\$2{,}500=\$12{,}500$. By equation 5, $E=pp_1p_0N=\$25$, the expected net profits per acre for each acre of the ranch

$$\text{where } p=\frac{1}{10},$$

$$p_1=\frac{1}{5},$$

$$p_0=\frac{A}{L}=\frac{1}{10}.$$

Obviously a well is not advisable at present so it is desired to hold the ranch until geophysical work can be done. Therefore, the operator is justified in paying ordinary interest rates on E to hold the property and a fair rental would be 5 per cent of $25 or $1.25 per acre per annum.

Problem V (Class II acreage).—A 1,000-acre block is located on or near a projected trend. Productive acreage in this territory should produce 40,000 barrels of oil per acre and require a drilling and exploratory expenditure of $4,000 per acre. Operating profit (r) during the period of production is estimated at 40 cents per barrel. Providing a closure exists under the acreage it has an excellent chance of being productive, 4 in 5. What is a reasonable price?

The geologist estimates that the trend can pass no farther than 3 miles south of the center of the property, or more than 4 miles north of the same point; that is, the trend can occur anywhere over a strip b_1, 7 miles in width (Fig. 1). The block is rectangular in shape, lies obliquely to the suspected trend and its projected width a_1 is 1.4 miles.

Using equation 6, we have

$$\frac{a_1}{b_1}=\frac{1.4}{7}=\frac{1}{5}$$

where p is given an excellent rating, $\frac{4}{5}$,

p_1 the chance for a closure on the trend, $\frac{1}{4}$,

$p_0=1$, since the probable pool exceeds 1,000 acres,

P_1 the chance that the trend extends this far, $\frac{1}{3}$.

By equation 1, $N=\$.40\times 40{,}000-\$4{,}000=\$12{,}000$, net profit per acre for a sure-shot of this type.

Therefore, by equation 6, $E=\frac{1}{5}\times\frac{4}{5}\times\frac{1}{4}\times 1\times\$12{,}000\times\frac{1}{3}=\$160$, the expected net profit per acre. A fair annual rental is 5 per cent of $160 or $8 per acre annually.

Problem VI (Class II acreage).—Two faults in different areas have trends indicating they may intersect in a given district. If this intersection can be located, it is a fairly certain chance, $\frac{9}{10}$, that production

will be obtained on one side of the intersection. The estimated yield is 20,000 barrels per acre, drilling costs $1,500 per acre, and operating profit (r) 50 cents per barrel. What price should be paid for the property shown in Figure 1?

The estimated limits of the two faults are shown in the figure where $a_1 = 1.65$ miles,
$b_1 = 2.6$ miles,
$a_2 = 1.5$ miles,
$b_2 = 2.2$ miles,
area of property = 1 square mile,
area $mnqrst = 2.3$ square miles.

The probabilities that the faults extend into the property are assumed to be $P_1 = \frac{1}{2}$ and $P_2 = \frac{1}{3}$; $P_0 = \frac{1}{2.3}$ area relationship.

From equation 7

$$p_1 = \frac{1.65}{2.6} \times \frac{1.5}{2.2} \times \frac{1}{2} \times \frac{1}{3} \times \frac{1}{2.3} = \frac{2.47}{79},$$

$p = \frac{9}{10}$,

$p_0 = 1$, since the expected pool is greater than one square mile,

$N = \$.50 \times 20{,}000 - \$1{,}500 = \$8{,}500$ net profit per acre for a sure-shot.

Hence $E = \frac{9}{10} \times \frac{2.47}{79} \times 1 \times \$8{,}500 = \$240$, the expected net profit per acre.

However, the faults may intersect in the middle of the property, and half may be productive and half barren. Because of this possibility we halve the expected net profit and call the probable value of the net profit per acre now $120. A fair annual rental would be 5 per cent of $120 or $6.

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HEBRON GAS FIELD, POTTER COUNTY, PENNSYLVANIA[1]

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ABSTRACT

The Hebron gas field was discovered in 1931, has been completely developed with the exception of possible extensions and is now approaching the final stage of depletion. Gas is produced from the Oriskany sandstone which was discovered as a producing horizon in this general territory in 1930. Gas occurs in a narrow, elongate closure on one of the long, sinuous, parallel anticlines characteristic of folding in the northern Appalachian province. Geologically and economically, this field is typical of other small, high-pressure, readily depleted Oriskany fields of northern Pennsylvania and southern New York, which have been in the process of discovery and development since 1930.

INTRODUCTION

The Hebron gas field is situated in north-central Pennyslvania in Hebron Township, Potter County. It is approximately 35 miles southeast of Bradford and 175 miles northeast of Pittsburgh.

Gas has been produced in this township from several shallow sands for more than 30 years. However, it was not until December, 1931, that gas was found in the Oriskany by Robert Hungiville *et al.* in Booth No. 1 at a depth of 4,924 feet. The development of large open-flow and high-pressure gas production from this sand has given the field considerable economic importance in the north Appalachian region.

The field as outlined in March, 1936, may be considered nearly developed, although a few more wells drilled along the south side of the field may prove a productive area.

STRATIGRAPHY

The surface rocks in the field belong to the Chemung group and the Cattaraugus formation of the Devonian system. Only the upper 100–200 feet of the Chemung is exposed along the crest of the closure. It is made up of greenish gray alternating fine-grained sandstones, sandy shales, and shales. The Cattaraugus is approximately 500 feet thick and, in whole or in part, is exposed along the flanks and ends of the closure. It is composed predominantly of red sandstones and red shales. The division between the Chemung and the Cattaraugus is

[1] Manuscript received, May 4, 1936.

[2] Penn-York Natural Gas Corporation.

indefinite, and is determined by color change and a general lithological difference between the sandstones of each. A few miles south of the field the Oswayo formation, approximately 1,000 feet thick, is fully exposed and is assumed to be the highest member of the Devonian represented here.

All the unexposed rocks down to and including the Oriskany are Devonian. In the Potter Development Company's J. W. Matteson well in the southwest corner of Hebron Township, the Oriskany horizon was found from 5,174 to 5,179 feet and Fettke[3] has identified 66 feet of very dark, brownish gray siliceous limestone from 5,179 to 5,245 feet as Helderberg. From the base of the Helderberg to 5,528 feet brownish gray argillaceous dolomites are very probably of Silurian age, and salt and dolomitic limestone from 5,528 to 5,550 feet, the total depth, are probably Camillus.

The total thickness of the Devonian as represented in this field, including all of the Cattaraugus and Oswayo formations, is approximately 6,800 feet. Below the Devonian are probably 8,000 feet of Silurian, Ordovician, and Cambrian sediments, most of which are exposed within 100 miles of Potter County.

In sample well logs, the Canaseraga sandstone, Genesee shale, Tully limestone, Marcellus shale, Onondaga limestone, and Oriskany sandstone are commonly recognized, the divisional limits of the Tully, Onondaga, and Oriskany formations being sharply defined. From the top of the Chemung downward for 3,000 feet, most of the section is composed of sandstones and sandy shales, within which it is very difficult to identify members as they are known at their outcrops. The one exception is the Canaseraga sandstone.[4] At its type locality at Canaseraga, New York, 45 miles northeast of the Hebron field, this formation is about 150 feet thick, the upper 50–75 feet of which is a massive ledge- and bench-forming sandstone member which may be traced on the surface throughout the western part of Steuben County, New York, into Tioga County, Pennsylvania.

This upper massive sandstone is recognizable in sample logs of wells near its outcrop at Canaseraga and in western Steuben County, whence it may be traced into Potter and McKean counties, Pennsylvania. After extensive surface and sub-surface work H. E. Boyd[5] has correlated it with the Waugh and Porter oil sands of southern

[3] Charles R. Fettke, "Subsurface Devonian and Silurian Sections Across Northern Pennsylvania and Southern New York," *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 601–60.

[4] G. H. Chadwick, "The Stratigraphy of the Chemung Group in Western New York," *New York State Mus. Bull. 251* (1924), p. 150.

[5] H. E. Boyd, Penn-York Natural Gas Corporation, Coudersport, Pennsylvania.

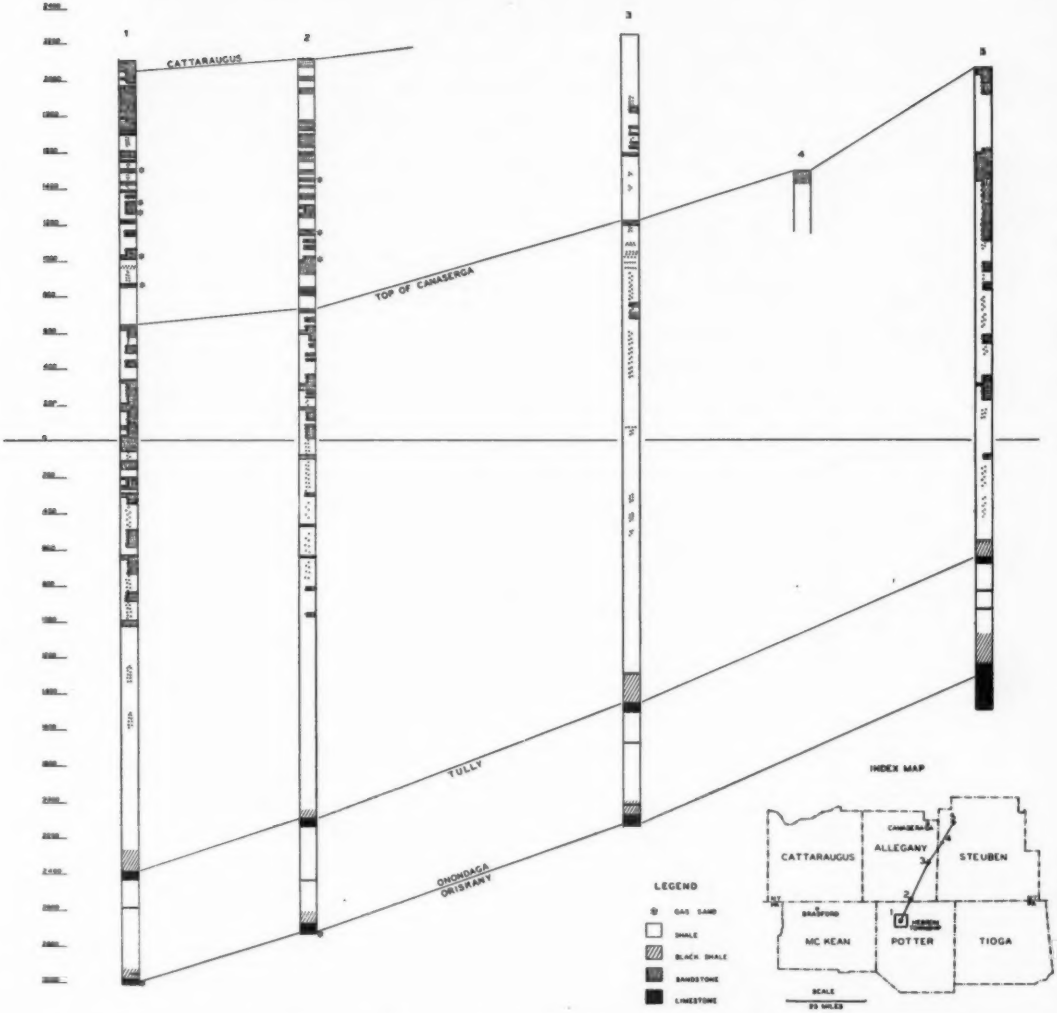

FIG. 1.—Cross section from northwestern Steuben County, New York, to Hebron Township, Potter County, Pennsylvania. Numbers represent logs and outcrop as follows. 1—Composite-sample well log of Hebron field. 2—Composite-sample well log of State Line field of Allegany and Potter counties. 3—Johnson and Williams, Randolph No. 1, Alfred Township, Allegany County, sample well log. 4—Outcrop of Canaseraga sandstone about 3 miles northwest of Hornell, New York. 5—Gas States Corporation, Magin No. 1, Dansville Township, Steuben County, sample well log. Location of this well is at approximate top of Canaseraga.

Allegany County, New York, and the Bradford oil sand of Cattaraugus County, New York, and McKean County, Pennsylvania. This member is present in the State Line field of Allegany and Potter counties, and in the Harrison, Ellisburg, and Hebron fields of Potter County. In the Hebron field it is about 60 feet thick. The upper 20–30 feet is fine-grained sandstone and the lower 30–40 feet interbedded sandstones and sandy shales. The top of it is approximately 1,420 feet below the base of the Cattaraugus and approximately 3,030 feet above the top of the Tully.

On the assumption that the Canaseraga is the lowest member of the Chemung of the Genesee Valley region, that the 60-foot section of the Hebron field is the upper member of the Canaseraga, and that the total thickness of the Canaseraga is 150 feet, the thickness of the Chemung in this field is 1,570 feet. In the Matteson well Fettke[6] places the base of the Chemung at 2,553 feet though in the same well the writer places the base of the Canaseraga at about 1,700 feet.

Gas has been and is being produced in the western part of Hebron Township from shallow sands of the middle and lower parts of the Chemung group. The two most persistent of these are about 1,050 and 1,200 feet below the base of the Cattaraugus. The lower sand is 210 feet above the top of the Canaseraga or Bradford sand, which in this field does not produce oil or gas.

The Oriskany is the only Devonian formation below the Chemung which produces gas in this field. It is composed of quartz sand grains 0.1–2.0 millimeters in diameter, many of which are well rounded and etched. The cementing materials are calcium carbonate and silica. The latter is more common in the upper 1–4 feet of the formation which is usually hard and non-porous, and the former is distributed through the remainder of the formation, more commonly in the lower part. Gas "pays" range from 4 to 12 feet thick and occur immediately under the hard upper zone. The formation in this field is known to vary in thickness from 0 to 30 feet and its maximum probably does not exceed 35 feet. The porosity of samples blown from wells varies from 9 to 14 per cent.

The Oriskany is present and produces only in the northeastern half of the closure. In the southwestern half it is absent or is represented by a few feet of detrital material composed of rounded sand grains, shale, and a green mineral, not identified but probably glauconite. The green mineral is common at the Onondaga-Oriskany contact in this region and is almost everywhere present even though the sand is absent. As nearly as can be determined the border between

[6] Charles R. Fettke, *op. cit.*, pp. 601–60.

these two areas in the field extends northwest and southeast. The most probable reason for the absence of the Oriskany sand is that it was not deposited. The small area of the Hebron field where the sand is absent is only a part of a much larger area on the south and west which also appears to be barren of sand. These barren areas are common in New York and Pennsylvania.

STRUCTURE

The Hebron closure is 1.5 miles wide and 12 miles long, northeast and southwest, and is part of the Hebron anticline which may be traced through Pennsylvania and New York for 75 miles or more. The closure plunges several hundred feet at its southwest end but declines only 250 feet at its northeast end into a saddle between it and the Ellisburg closure. The highest part of the closure is about 1,500 feet above the lowest part of the parallel syncline, about 4 miles south of the axis, and nearly the same amount of decline into a similar syncline exists on the north flank.

This anticline with its closure was formed at the time of the Appalachian revolution at the close of the Paleozoic and is part of the parallel system of sinuous folds characteristic of the Pennsylvania region. It is not believed that the Hebron and adjacent anticlines have been further folded since the close of the Paleozoic.

The average rate of dip of the surface beds down the north flank of the closure is 300 feet per mile—about 3°—and that for the south flank somewhat greater, especially within a narrow belt parallel with, and 0.5–1 mile south of, the axis where the dips may be as steep as 20°. Considerable difficulty exists in detail and exact mapping of the surface structure because of the discontinuous key beds and lack of large, firm, and non-cross-bedded outcrops.

The structure of the Oriskany corresponds very closely in amount and direction with that of the surface beds, except possibly along the south flank where the lower part of the Devonian section may be faulted. The axis of the closure does not appear to shift with depth.

Near the northeast end of the closure an exceptional structural difference on the Oriskany of approximately 300 feet between closely adjacent wells, and in the structurally low wells an increase of 100 feet or more in the normal 605-foot interval at this point between the top of the Tully and the top of the Oriskany, are the only evidences of a fault. In this critical area a 45° dip of the Onondaga and Oriskany could account for all of the sharp structural difference and increase now known in the Tully-Oriskany interval. By comparing the insufficient data available here with the Tioga closure of Tioga County,

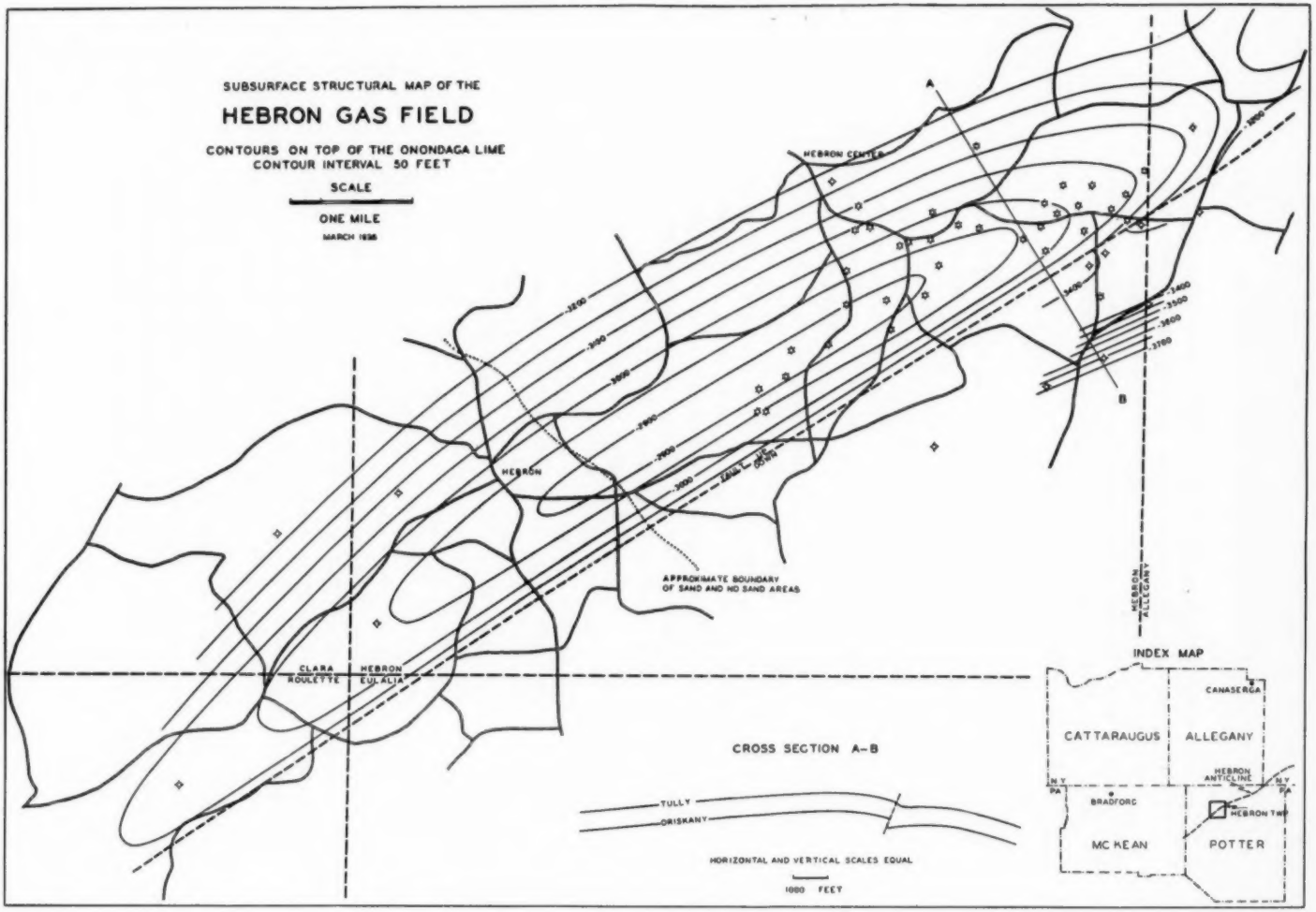

FIG. 2.—Subsurface structure of Hebron gas field.

Pennsylvania, 40 miles east of the Hebron field, where faulting is definitely established in the same structural position, it is not unreasonable to interpret similar faulting at Hebron, although probably on a lesser scale. It is noteworthy that the critical area at Hebron directly underlies the belt of unusually steep dips of the surface beds. If it is assumed that a fault exists at Hebron, it is very likely that displacement gradually decreases upward and dies out 1,000 feet or less above the Oriskany, that crushing and internal adjustment of the soft Hamilton shale beds between the Onondaga and Tully accounts for part of the increased thickness of this section, and that the fault parallels and extends the full length of the closure with the greatest displacement opposite the highest part of the closure.

Whether sharply and steeply folded or faulted, from the standpoint of development, this narrow critical belt bounds the productive southeast side of the main field and operators usually have been careful to avoid drilling wells on the low side of it.

Near the northeast end of the field, less than 0.5 mile southeast of this critical belt, gas was found, in one well in the Oriskany, approximately 250 feet lower than the original gas-water line on the main closure but 50 feet or more higher than in wells along the low side of the belt. This suggests the existence of a lower and parallel subsidiary closure which may not be reflected in the surface beds.

The accumulation of gas in the Oriskany is due to closure and its distribution to the salt water below the gas, and the presence or absence of sand. The original gas-water contact existed at approximately −3,115 feet or 230 feet below the highest producing well. The contact probably had a common level for all sides of the field. With the depletion of gas, the water level has risen about 25 feet and probably will continue to rise until ultimately a large part of the producing area will be flooded.

GAS PRODUCTION

The shallow producing sands are generally characteristic of the Devonian producing horizons in the old fields of Pennsylvania and are composed of very fine-grained sandstones interbedded with sandy shale. Porosity seems to be extremely variable. Ready permeability to the flow of gas is ordinarily absent. Porosity is more important than structure in controlling accumulation.

The production of gas has been of much more economic importance from the Oriskany sand than from the shallow sands. Forty-six wells have been completed in the Oriskany in this field, of which 37 have produced gas and 9 have been dry. In addition, 4 other wells

were begun but were abandoned before reaching the Oriskany. This drilling by years has been as follows.

Year	*Gas Wells*	*Dry and Abandoned Wells*
1931	1	0
1932	5	2
1933	6	7
1934	20	3
1935	5	1
Total	37	13

The closed well-head pressure of the first wells completed in this field was 2,150 pounds per square inch and the pressure had declined by January 1, 1936, to approximately 500 pounds per square inch. The pressure decline has been remarkably even for all wells in the field whether producing or shut in. Initial open flows have varied from 2.5 million to 40 million cubic feet daily, the average for all wells being 13 million cubic feet.

The producing area of the Oriskany is approximately 3,800 acres. The productive limits of the north and south sides and the east end of the field are well defined but the exact western limit, bounded by the absence of sand, has not been definitely determined. The productive area of the main closure probably will not exceed the figure given. However a new productive area may be developed south of, and adjacent to, the main field as now outlined.

The total production of the field to January 1, 1936, including gas lost was approximately 34 billion cubic feet and the ultimate production probably will not exceed 40 billion cubic feet or an ultimate average per acre of 10.5 million cubic feet.

The Oriskany gas from this field is sweet, dry, and has a methane content above 90 per cent. It has a heating value of approximately 1,030 B.T.U.

PRODUCTION PRACTICE

All drilling has been done with cable tools, using steam for power almost exclusively. The average drilling time per well has been 80 days.

The most common casing program has used 30–60 feet of 10- or $12\frac{1}{2}$-inch surface pipe, 600 feet of $8\frac{5}{8}$- or $9\frac{5}{8}$-inch light-weight casing for the water string and 5,100 feet of 26- to 30-pound, 7-inch, grade D seamless casing. The production- or 7-inch string of casing is run in a dry hole and the lower 100–800 feet cemented either by circulation or displacement. The 7-inch casing is set in the Onondaga limestone a few feet above the Oriskany sand. Tubing has not been used commonly in these wells.

The surface equipment ordinarily consists of a 7-inch drilling gate and three 4-inch flow-control gates or a combination drilling gate with two built-in 4-inch outlets with 4-inch gates for flow control, all such equipment being tested to 4,000 pounds per square inch or more.

Control of gas flow has been managed with reduction orifice disks, regulators in tandem, or both. Heaters have been required with the regulators and in some cases with the reduction disks. The gas from nearly all wells has been accompanied by a small amount of fresh water which has caused some freezing trouble.

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GEOLOGY OF NORTHWEST BASIN, WESTERN AUSTRALIA[1]

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ABSTRACT

Ten years ago it was thought that the Northwest Basin of Western Australia had only one of the many requisites for oil accumulation, namely, porous sandstone. Now it is apparent that there is 7,000 feet—rather than 2,000 feet—of Permo-Carboniferous strata; that although there are several thick sandstone formations, only 40–55 per cent—instead of almost all—of the Gascoyne series is sandstone; that although cover rock was thought once to be practically absent, the situation now seems vastly better not only in various horizons of the Permo-Carboniferous but also in parts of the Cretaceous; and finally, that the deposits of the source-bed type appear adequate. Also, there is abundant evidence of profuse life during much of Permo-Carboniferous time despite probable cool sea temperatures or successive glacial stages.

In view of recent studies in Western Australia one should have an open mind in regard to oil possibilities both in Western Australia and other areas of late Paleozoic in Australia.

INTRODUCTION

This paper is presented in order to convey a picture of a remote, rarely visited area in the northwestern part of Australia, known geologically as the Northwest Basin, one of several extensive areas of marine, late Paleozoic strata situated in the peripheral part of the continent. Particulars now in hand differ widely from published descriptions of earlier observers. These differences have an important bearing on oil possibilities and, therefore, merit publication in some detail.

The region is a long, narrow coastal strip extending 400 miles north and south, with an average width of 100 miles and an approximate area of 36,000 square miles. Its position with reference to Desert Basin, a much larger area of related rocks to the northeast, is represented on the accompanying sketch map, Figure 1.

The basin is composed of Permo-Carboniferous, Mesozoic, and Tertiary strata with regional westward, but undulatory, dip, resting on pre-Cambrian basement rocks such as constitute the greater part of Western Australia. The approximate distribution of the several sedimentary systems is represented on the map, Figure 2.

[1] Published through courtesy of the managing director, Oil Search Limited, Sydney, Australia. Manuscript received, May 13, 1936.

[2] Oil Search Limited.

SURFACE FEATURES

Excluding the peninsula of Northwest Cape, the area may be described topographically as consisting of a plain rising gently from low elevations near the coast to an elevation of about 800 feet, 60–80 miles inland, and still higher farther east. Rising above this plain are various flat-topped hill ranges, chief of which, from north to south, are the Moogooloo, Kennedy, Bidgemia, and Carrandibby with elevations

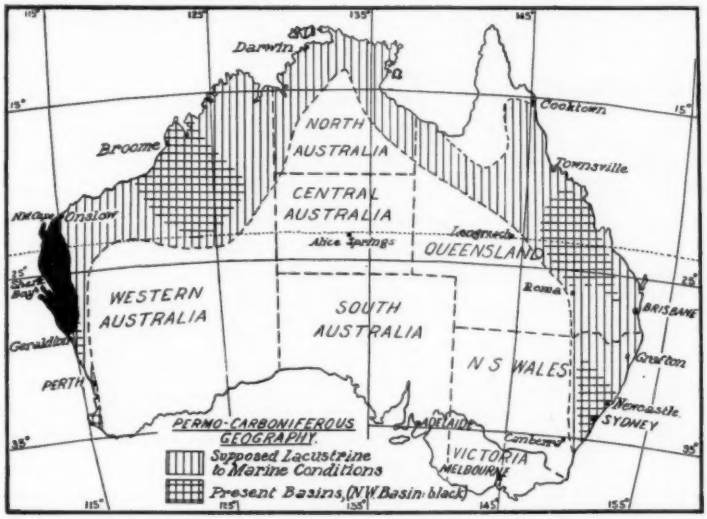

FIG. 1.—Sketch map of Australia showing Permo-Carboniferous geography (Northwest Basin in black).

ranging from 1,100 to 1,200 feet. These ranges are erosion remnants of a formerly continuous seaward sloping surface. The Kennedy Range has a width of 25 miles at its widest part, but the others are much less extensive.

The Northwest Cape Range and lesser hill ranges near the coast have rounded profiles such as go with folded ridges more or less dissected by erosion. The Cape Range is 65 miles long and rises to an elevation exceeding 1,100 feet.

The climate is semi-arid with a rainfall of barely 11 inches. Extensive areas, notably near the coast, are covered by sand dunes. Many wells have been drilled in the basin for artesian water and their logs are helpful in the study of subsurface stratigraphy.

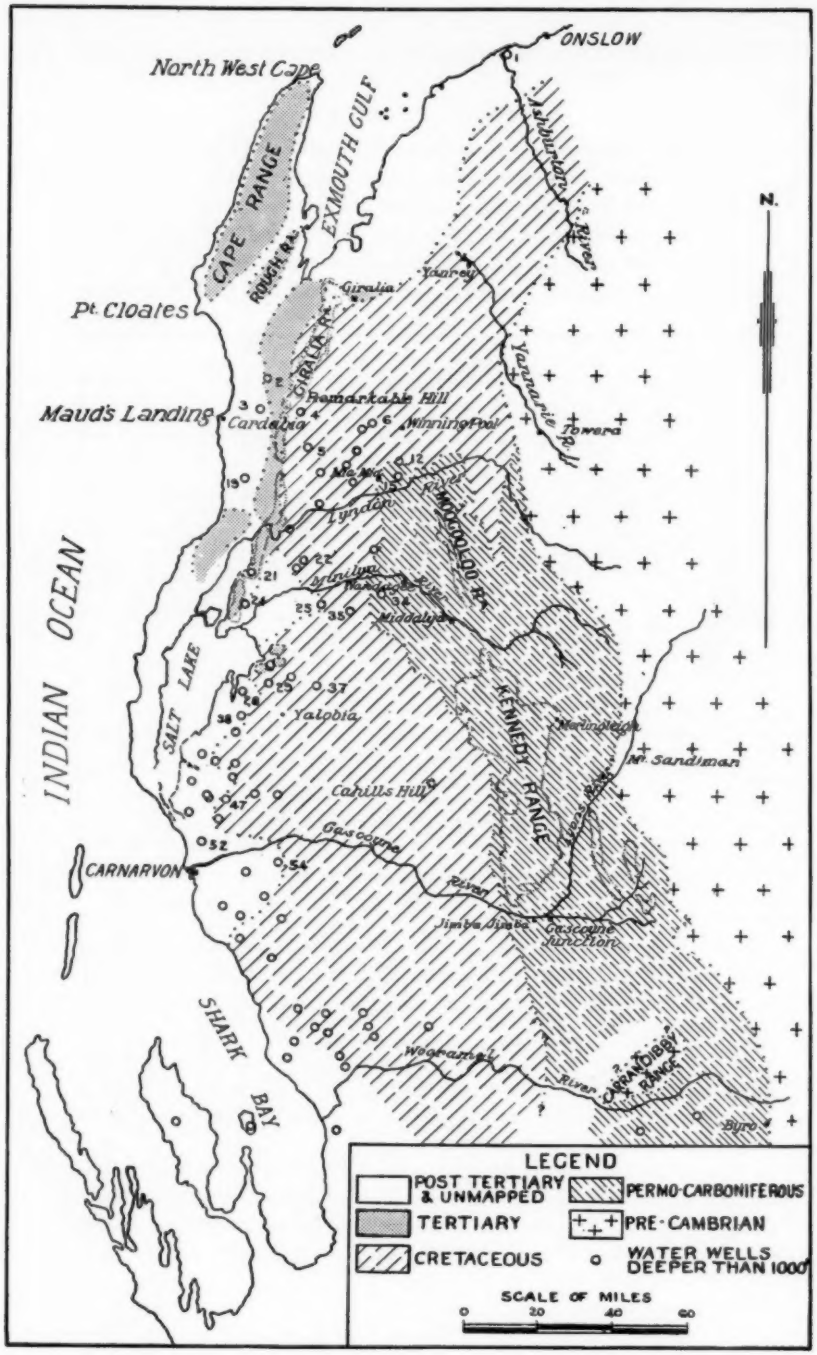

FIG. 2.—Geologic sketch map showing all but southernmost part of Northwest Basin.

PREVIOUS WORK

The Permo-Carboniferous sequence up to the top of the Kennedy sandstone was described in general terms by Maitland 25 years ago (1, 2, 3).[3] His principal contribution to the geology was the recognition of glacial beds in the lower part of the section which he named the Lyons conglomerate. He also recognized the artesian water possibilities of the region; consequent on this discovery the deep well at Pelican Hill (Fig. 2, well location 52) was drilled and yielded an artesian flow.

F. G. Clapp, who visited this and other sedimentary basin areas in Western Australia in 1924, published three papers (4, 5, 6), one setting forth general observations and two dealing mainly with oil prospects. His discovery of folded Tertiary strata in the Cape Range was a noteworthy contribution. So far as the Permo-Carboniferous is concerned his observations apply to the same units described by Maitland, but he found additional outcrops of glacial beds. He concluded that the region has no possibilities for oil and his published comment on this and all other basins in Western Australia has been widely accepted as decisively condemnatory.

The geological map of the Commonwealth, by T. W. E. David, published in 1932 (7), incorporating data from the map by the State Geological Survey, is largely inaccurate not only as to the distribution of the stratigraphic units in this part of Western Australia, but also as to their ages. For example, the broad central belt of outcrop represented as Jurassic is now known to be wholly Cretaceous. Moreover, these beds, as illustrated in Figure 2, extend over an area more than double that represented on previous maps.

Current interest in the area, from the economic viewpoint, may be said to have started with studies by Rudd in the Wooramel River district in 1932, which established the fact that parts of the exposed stratigraphic section had not been observed by earlier visitors. Following a reconnaissance by Condit and Rudd in 1934, more critical studies were carried out by Raggatt on two trips in 1934–35, during one of which he was accompanied by K. Washington Gray of the Anglo-Iranian Oil Company. The results of the several trips are summarized briefly in a recent paper by Condit (8). Credit is due to Raggatt for much of the stratigraphic material now presented. He was the first to discover and describe the true stratigraphic relationships of the higher formations of the Permo-Carboniferous.[4]

[3] See Bibliography at end of article.

[4] The geology of this region will be presented in greater detail in a paper by Raggatt to be published by the Royal Society, New South Wales.

TABLE I

GENERALIZED STRATIGRAPHIC SECTION

Age	*System*	*Thickness in Feet*	*Description*
Post-Tertiary			Shelly sands; oölitic limestones and travertinized sands; dune sands
		Unconformity	
	Mio-Pliocene		White, coralline and foraminiferal limestone and travertinized sands
	Miocene?	100	Well bedded, white, foraminiferal limestone
Tertiary	Lower Miocene–Upper Oligocene?	600	White, pink and yellow *Lepidocyclina* limestones
	Eocene	10–30?	Detrital limestone with *Discocyclina* and *Nummulites*
		Disconformity?	
Cretaceous	Cardabia series (Campanian-Turonian)	855–1,050	Mainly chalks and marls; polyzoal limestones and glauconite sand with *Ammonites* in upper part; shales crowded with *Inoceramus* in lower part
	Winning series (Albian)	100–1,240	White and vari-colored punky silts, radiolarian cherts and glauconitic sandstones
		Unconformity	
Permo-Carboniferous	Gascoyne series	4,250–5,000	Limestones, sandstones, and shales divided into following formations. *Wandagee formation.*—Shale, argillaceous sandstone, and sandy limestone; occasional small glacial erratics (?); marine; thickness 1,250–1,450 feet *Kennedy sandstone.*—Massive in central part of area, tending to shaly in north; marine; thickness 400–700 feet *Byro formation.*—Mainly marine, argillaceous sandstone; sandy shales in upper half, thin-bedded sandstones (marine) and sandy to carbonaceous shales in lower half; decreasingly sandy northward; mainly marine but fresh water in part; occasional small erratics toward base; thickness 2,300 feet in north and 600 feet on Wooramel River *Wooramel sandstone.*—Thin quartz pebble bands; sparse marine fauna; thickness 130–280 feet in north and 800 feet on Wooramel River *Callytharra limestone.*—Flaggy limestones and calcareous shaly mudstones; richly fossiliferous; thickness 200–460 feet in north and 85 feet on Wooramel River
		Disconformity?	
	Lyons series	2,150–2,400	Upper 300 feet mainly sandy shales with sandstones and limestones; remainder fine-grained sandstone with glacial boulder beds and some shales; glacial erratics up to 12 feet in length; marine fossils at intervals
		Unconformity	
Pre-Cambrian	Mosquito series	—	Schists and phyllites intruded by granite

GENERAL STRATIGRAPHIC SUMMARY

Table I is a generalized section of formations present in the area.

No igneous rocks other than those of the Basement complex have been reported in this region nor are any large intrusive masses known anywhere in the Paleozoic of Western Australia. The geologic map, Figure 2, shows the distribution of the major stratigraphic units. Boundaries south of the Wooramel River have not been mapped. The pre-Cambrian border is taken in part from the map of Western Australia issued by the State Geological Survey in 1933.

PERMO-CARBONIFEROUS STRATIGRAPHY

INTRODUCTION

Overlying the Mosquito series and underlying the Cretaceous is a considerable thickness of sediments, dominantly marine, within which there is no marked break either faunal or tectonic. Except for the evidence of glacial conditions in the lower part, the record is one of more or less continuous deposition under oscillating conditions, similar lithological types being repeated.

Although in terms of European time equivalents there is no marked faunal break, there are differences in the faunal content. For instance, *Dibunophyllum*, *Aetomacladia ambrosioides*, and *Rhombopora tenuis*, regarded by Chapman as typical Upper Carboniferous forms, are restricted to the Lyons and Callytharra beds though *Orthis* (*Rhipidomella*) cf. *australis* which is found in the Burindi series (Lower Carboniferous) of New South Wales occurs only in the Lyons series of the west. Other Carboniferous fossils, for example, *Cleiothyridina macleayana*, *Spirifer byroensis*, *Chonetes hardrensis*, *Productus semireticulatus*, and *Plerophyllum australe* are found, however, in the Byro, some being high in that formation, and *Chonetes pratti* occurs in the Byro and Wandagee beds.

Of fossils characteristically Permian, *Spirifer byroensis*, *Chonetes hardrensis* var. *cracowensis*, and *Tribrachyocrinus* sp., are confined to the Byro beds, and *Cardiomorpha blatchfordi*, *Aviculopecten*, *Spirifer musakheylensis*, and *Strophalosia clarkei* are not found below the Wooramel sandstone. *Deltopecten subquinquelineatus* (*comptus*), common in the upper Marine of New South Wales, is known only in the middle of the Byro, and *Spirifer rostalinus* var. *crassa* only from the Wandagee beds. *Linoproductus concriniformis* which is not found below the Permian in Europe and India occurs in the same beds as *Deltopecten subquinquelineatus*.

It is surmised that the Olive shales of Woolnough and Somerville

(9) on Irwin River, 100 miles south, with their well known cephalopod beds apparently are correlated with the shales forming the upper part of the Lyons series. The latest identification of this cephalopod as *Metalegoceras jacksoni* (7, see Addenda) gives a distinctly Permian aspect to the whole sequence above the main glacial beds (Lyons series).

Summarizing, it will be noted that Permian forms occur down at least to the base of the Wooramel; the faunal aspect of the Lyons series is Carboniferous; and some forms elsewhere, occurring in the Carboniferous only, range well up in the sequence.

GENERAL RELATIONSHIPS

The Permo-Carboniferous occupies an area of about 5,000 square miles from Gascoyne River northward. On the Yannarie and Ashburton rivers Cretaceous beds overlap the Permo-Carboniferous and rest on the basement. A well drilled (depth 1,728 feet) at Onslow (Fig. 2, well location 1) apparently did not enter the Permo-Carboniferous. Data of wells farther south furnish evidence of the extension of the Permo-Carboniferous westward beneath the cover of younger sediments.

The contact of the Permo-Carboniferous and pre-Cambrian is locally faulted, but for the most part is one of normal deposition upon a basement which had been subjected to prolonged erosion.

Wherever the Permo-Carboniferous rocks are found to be overlapped by younger strata those beds are, with one possible exception, Cretaceous. Good outcrops of the contact are rarely seen but it is a common experience to find every exposure of Permo-Carboniferous in a given area dipping at angles up to 22° and neighboring Cretaceous exposures with no appreciable dip. Differences in dip in exposures a few miles apart are commonly about 10°. Along the west base of the Kennedy Range, Cretaceous beds are down-faulted against the Kennedy sandstone.

Sections based on a study of the logs of the many wells drilled in the deeper part of the basin suggest that before Cretaceous deposition the Permo-Carboniferous was folded into broad structures which then suffered denudation. The Cretaceous was deposited on a rather uniform base, and the succeeding Tertiary deposition followed with comparatively little deformation, the warps controlling the locus of the new ones. There appears to be only slight angular discordance between the Permo-Carboniferous and higher systems in the deeper parts of the basin.

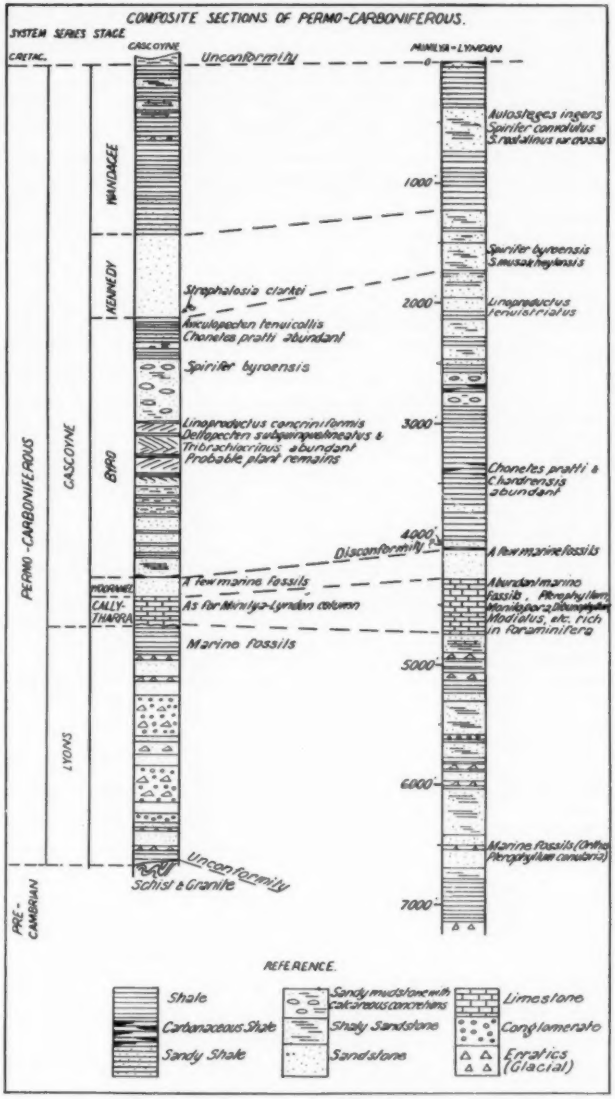

FIG. 3.—Generalized sections of Permo-Carboniferous on Gascoyne River and in Minilya-Lyndon River area.

PERMO-CARBONIFEROUS FORMATIONS

GASCOYNE SERIES

Wandagee formation.—Thickness 1,250 to 1,450 feet; shales, sandstones, sandy mudstones and limestones divisible into an upper unit of thin-bedded friable sandstone and sandy limestone, and a lower unit largely shale (as much as 500 feet of continuous shale being present in basal part at type locality); principal fossils are *Aulosteges ingens, Spirifer rostalinus* var. *crassus;* also *S. marcoui, S. convolutus, Chonetes pratti* which are abundant in restricted horizons.

Kennedy sandstone.—Maximum known thickness 700 feet, thinning northward; almost wholly sandstone but tending toward shaly sandstone northward; includes dense blocky, ferruginous, well bedded, white, micaceous beds and fine-grained yellowish brown types; ferruginous fossil casts and concretions found locally; *Strophalosia clarkei* perhaps commonest fossil; others are *Spirifer byroensis, S. musakheylensis, Cardiomorpha blatchfordi.*

Byro formation.—Thickness not less than 2,400 feet from Gascoyne northward and 600 feet on Wooramel River; exposures on Gascoyne River in descending order show: (a) massive, sandy, micaceous mudstone with large calcareous lenses and dark to sandy shales; *Spirifer byroensis* plentiful; (b) cross-bedded, thin-layered, brown to greenish brown sandstone with abundant small spherical concretions and abundant *Deltopecten* aff. *subquinquelineatus* and *Tribrachyocrinus* sp.; (c) sandy mudstones, dark shales and friable white sandstone members; (d) sandy limestone, calcareous sandstone and dark shales with a few small glacial erratics; (e) carbonaceous shale at base. The sandy mudstones (a) persist northward to Minilya River but other strata give way almost entirely to dark to carbonaceous and sandy shales; data of wells still farther north suggest that the entire formation is shaly with some calcareous beds; carbonaceous matter and probable plant remains in dark shales interbedded with marine strata; in addition to the *Deltopecten*, commonest fossils are *Chonetes hardrensis* and *C. pratti.*

Wooramel sandstone.—Thickness 180–230 feet in north and 800 feet on Wooramel River; mainly medium-grained, white, micaceous sandstone, locally cross-bedded at top; shaly sandstone in lower part in some northern sections; occasional poorly preserved marine fossils.

Callytharra limestone.—Thickness 85 feet on Wooramel River, 200–460 feet in the north (probably as much as 650 feet westward under cover); commonly divisible into upper flaggy limestone and lower calcareous shaly mudstone with thin, hard limestone bands; rich and varied marine fossil content including *Plerophyllum, Monilopora, Dibunophyllum, Phialocrinus, Evactinopora, Syringothyris, Seminula, Cleiothyridina, Modiolus,* and *Warthia; Fenestellidae* abundant in shaly beds.

LYONS SERIES

Thickness 2,150–2,400 feet; divisible into two unequal portions on Gascoyne River, an upper shaly group with thin fossiliferous limestone beds and glacial erratics, and a lower more sandy group with not less than eight distinct glacial conglomerates, with abundant erratics and striated pebbles; becomes more shaly northward; marine fossils at intervals, including *Fenestella propinqua, Conularia warthi, Plerophyllum australe,* and *Orthis* (*Rhipidomella*) cf. *australis.*

There is possible disconformity between the Wooramel and the Byro and between the Callytharra and the Lyons; otherwise the units are conformable.

The thickness of Permo-Carboniferous strata exposed on Gascoyne River and its tributaries is about 6,750 feet and the thickness on Lyndon River (including well data) is 7,350 feet.

It will be observed that the sequence falls naturally into two divisions, a lower consisting largely of fluvio-glacial beds, in part marine, and an upper composed of shales, sandstones, and limestones. As these are major subdivisions of a system, they are termed *series*, the glacials

being designated the Lyons series and the remainder the Gascoyne series.

The Gascoyne series is further divisible into units, largely but not entirely lithological. Thus, the Callytharra limestone, and the Wooramel and Kennedy sandstones are mainly lithologic units; the Byro and Wandagee beds are not, but consist of alternations of strata which for convenience are grouped together. These are important subdivisions of a series, and as such are to be described as formations.

LYONS SERIES

The Lyons series is defined as including all Permo-Carboniferous beds below the base of the Callytharra limestone. The series consists of 2,000–2,450 feet of strata which show evidence of having been derived more or less directly from neighboring areas being subjected to glaciation, the materials being largely of the fluvio-glacial type along with intermittent marine beds.

A section measured on Wyndham River shows at least 8 distinct glacial boulder beds closely resembling the one discovered by Maitland. There appears to be no certain lithological criterion for distinguishing one from another and, due to this similarity and the commonly prevailing low dip, doubtless the lower horizons have been confused with the original "Lyons conglomerate." Certainly outcrops on Kialawibri Creek, a tributary of Lyndon River, which have been referred to as the "Lyons conglomerate" are not less than 2,000 feet below the horizon of that name on Wyndham River. Whether or not any one of the several boulder horizons is persistent from place to place is unknown.

According to Rudd the contact of the Lyons with the Callytharra is conformable in the Wooramel River Valley. In the Gascoyne Valley there is a transition phase upward from the "Lyons conglomerate" through a limestone conglomerate to the Callytharra, but the possible equivalent of this conglomerate bed on Wyndham River is separated from the Callytharra by 300 feet of sediments, mainly shales. In general, the relationship between the upper Lyons and the Callytharra is none too well known because of the non-resistant nature of the beds. The marked parallelism in strike and general similarity of dip show, however, that there is no marked unconformity. What appear to be marked nonconformities locally may be glacial phenomena, such as distortion of substrata by grounded icebergs.

Denudation of the Lyons beds generally produces boulder strewn flat country with a few low mesas, the latter largely sandstone. The

country occupied by them carries little vegetation, the quartz pebble beds being particularly sparsely covered. As a consequence of this weathering the surface outcrops appear to be mainly boulder beds and unless the greatest care is taken in measurements, the amount of other sediments may be underestimated.

The Lyons series consists of sandstone, fluvio-glacial boulder beds, conglomerate and shale having a thickness of 2,000–2,400+ feet. A complete section exposed in the valley of the Wyndham, apparently free from repetition or deletion by folding or faulting, as measured by Raggatt, follows.

COMPLETE SECTION OF LYONS SERIES ON WYNDHAM RIVER, STRATA IN DESCENDING ORDER

	Thickness in Feet
Clay shale, fine-grained sandstone and calcareous conglomerate; a few glacial erratics near top; marine fossils	380
Boulder bed (original Lyons conglomerate of A. Gibb Maitland)	20
Mainly sandstone	160
Boulder bed	15
White micaceous sandstone	125
Boulder bed; shaly matrix, granite and silicified limestone erratics common; group of granite boulders observed with one individual 4 by 7 feet	350
Mainly white micaceous sandstone with some boulders up to 1 foot in diameter	50
Boulder bed; calcareous sandstone lenses 1–2 feet in length at base	110
Sandstone with thin beds of pebbles	90
White quartz pebble conglomerate with boulders	325
Sandstone	100
White quartz pebble conglomerate with boulders	85
Feldspathic (?) sandstone with a few quartz pebbles	50
White quartz pebble conglomerate (pebbles 1–4 inches in diameter)	25
Medium-grained, white, micaceous sandstone	140
Boulder bed; sandy matrix; largest boulder of granite 4 by 3 by 2 feet	20
Shale; gray and dense with calcareous concretions	40
Coarse grits to bouldery beds	40
Granitized schist (basement)	—
	2,165

An incomplete section measured in the Minilya River Valley shows a thickness of 2,445 feet. Here the boulder beds are relatively unimportant as compared with those of Wyndham River and the section is generally more shaly. The upward lithologic change in the sandstones from feldspathic to argillaceous types is noted here just as on the Wyndham.

A list of fossils found immediately above and below the top glacial boulder bed of the Lyons on Wyndham River is given by Maitland (3, page 35). For the paleontological descriptions one may refer to Etheridge's paper (10).

FOSSILS FROM LYONS SERIES ON WYNDHAM RIVER

Aviculopecten tenuicollis Dana	*Reticularia lineata* Martin
Hexagonella dendroidea Huddleston	*Cleiothyris* (*Athyris*) *macleayana* Eth. Fil.
Plerophyllum australe Hinde	*Chonetes pratti* Davidson
Spirifer musakheylensis Davidson	*Productus* cf. *longistriatus* Foord
Spirifer hardmani Foord	*Crinoidea*
Spirifer lata McCoy	*Bryozoa*

FIG. 4.—Weatherered outcrop of boulder bed about 80 feet above pre-Cambrian basement, on Wyndham River, a branch of the Gascoyne.

Among the fossils collected by Raggatt from the Lyons series on Lyndon River, F. Chapman identified the following from horizons 500–700 feet above the base of the series.

FOSSIL LIST FROM LYNDON RIVER

Fenestella propinqua deKon	*Chonetes pratti* Jno. Dav.
Crinoid ossicles cf. *Platycrinus*	*Orthis* (*Rhipidomella*) cf. *australis* McCoy
Conularia warthi Waagen	*Spirifer*
Plerophyllum australe Hinde	*Productus* (very abundant)

GASCOYNE SERIES

The name Gascoyne series, now proposed, includes all Permo-Carboniferous strata above the Lyons glacial beds. In more southern parts of the basin the series is composed of about 55 per cent sandstone, 30 per cent shale, and 15 per cent limestone, these percentages being based on outcrop measurements. North and west, all parts of the section become decreasingly sandy. The known thickness is be-

tween 4,250 and 5,000 feet. Formations in ascending order are Callytharra, Wooramel, Byro, Kennedy, and Wandagee.

Callytharra limestone.—At the type locality, Callytharra Spring on Wooramel River, the beds consist of argillaceous limestone or highly calcareous mudstone, including foraminiferal, crinoidal, and shelly types. Upstream on the same river the thickness is 85 feet. The beds strongly resemble the Fossil Cliff beds of the Irwin River Valley, 100 miles south.

FIG. 5.—Range of Callytharra limestone with small conical outlier of Wooramel Sandstone in center. Relief about 250 feet, north side of Arthur River, a branch of the Gascoyne.

From Wyndham River north to Lyndon River where the Permo-Carboniferous sediments pass under a cover of Cretaceous, a distance of 130 miles, the Callytharra beds form an almost continuous outcrop, either as a defined range, or series of ranges where faulting and folding have caused duplication. Since the usual dip is westerly, the outcrops (particularly of the upper members) take the form of westward facing ranges rising as much as 250 feet above the general level. These have a characteristically yellowish green color, as contrasted with the lighter tints of the overlying Wooramel sandstone.

In the southern part, the Callytharra beds are divisible into upper flaggy limestone and lower shaly beds. The upper part consists of alternations of hard, yellowish green, slabby limestone and shaly beds,

2–12 inches thick, and the lower of soft calcareous shaly mudstone with abundant *Fenestellidae* and few hard bands.

North of Minilya River this two-fold division has local variations. Thirteen miles southeast of Moogooloo Range a shaly zone, about 90 feet thick, separates two nearly equal flaggy members, and at Moogooloo Peak, the upper flaggy beds are overlain by shaly limestone with hard, lenticular, calcareous bands at the top.

The formation thickens progressively northwestward, the amount at Wooramel River being only 85 feet, that on Arthur River 275 feet, and in Moogooloo Range 460 feet. Westward from Moogooloo Range the thickness is considerably greater. The Mia Mia Five Mile or Jam Thicket well (Fig. 2, well location 15) is known to have passed through the Callytharra and the log suggests a thickness of 690 feet for the Callytharra.

Chapman's determinations of Rudd's fossil collections from Callytharra Spring on Wooramel River, the type locality, not previously published, are given here.

FOSSILS FROM TYPE LOCALITY OF CALLYTHARRA LIMESTONE

FORAMINIFERA

Dentalina labiata
Dentalina sp.
Spandelinoides striatoclavata
Trepeilopsis grandis
Calcitornella stephensi
Stacheia marginulinoides
Stacheia pupoides
Stacheia sp.
Ammodiscus incertus
Ammodiscus sp.
Palaeobigenerina sp.
Frondicularia woodwardi
Frondicularia sp.
Ruditaxis rudis
Globivalvulina plicata
Tetrataxis conica

COELENTERATA

Dibunophyllum (*Verbeekiella*) *talboti*
Plerophyllum australe
Plerophyllum sulcatum
Plerophyllum gregoriana
Plerophyllum sp.
cf. *Zaphrentis* sp.
rugose coral indet.

POLYZOA

Evactinopora dendroidea
Evactinopora crucialis
Dybowskiella sp.
Glyptopora sp.
Coscinium australe
Trachypora sp.
cf. *Pachypora*
Monilopora nicholsoni
Fenestella spinulifera
Fenestella pectinis
Rhombopora tenuis
Rhombopora multigranulata
Acanthocladia sp.
Aetomacladia ambrosioides
Streblotrypa etheridgei
Pinnatopora trilineata var. *texana*
Streblotrypa marmionensis
Polypora ampla

CRINOIDEA

Phialocrinus sp.
Rhipidocrinus sp.
cf. *Cyathocrinus* sp.
cf. *Hexacrinus* sp.
Platycrinus sp.

BRACHIOPODA

Spiriferella australasica
Cleiothyridina macleayana
Cleiothyridina sp.
Spirifer hardmani
Spiriferina cristata var. *decipiens*
Syringothyris exsuperans

Chonetes pratti
Strophalosia sp. nov.
Seminula sp.
Seminula randsii
Derbya cf. *bennetti*
Reticularia lineata
Schellwienella sp.
Productus semireticulatus
Productus punctatus
Linoproductus tenuistriatus var. *foordi*
Martiniopsis sp.
Taeniothaerus subquadratus
Aulosteges baracoodensis
Spirifer cf. *convolutus*
Spirifer cf. *duodecimcostatus*
Spirifer dubia
Spirifer musakheylensis var. *australis*
Dielasma hastata
Leptaena analoga

PELECYPODA

Nuculana sp.

GASTROPODA

Warthia sp.
Ptychomphalina maillandi

CEPHALAPODA

Orthoceras cf. *martinianum*

OSTRACODA

Healdia formosa
Healdia cuneola
? *Healdia* sp.
cf. *Kellettella* sp.
Bairdia sp.
Bairdia menardensis
Bairdia seminalis
Amphissites centronotus
Glyptopleura aff. *costata*
? *Cytherella* sp.

Chapman, through examination of fossils from various localities and horizons, concludes that the following genera are probably restricted to the Callytharra: *Monilopora*, *Dibunophyllum*, *Phialocrinus*, *Evactinopora*, *Syringothyris*, *Seminula*, and *Modiolus*. The assemblage of *Foraminifera* is regarded by him as similar to that of the Pokolbin beds of the Lower Marine series of New South Wales, and to indicate a close relationship to the Pennsylvanian of Texas and Oklahoma.

Wooramel sandstone.—On Wooramel River, Rudd found a sandstone about 800 feet thick resting on the Callytharra limestone, which he named the Wooramel. This is described as composed of fine-grained, micaceous, foliated, shaly sandstone, more or less massive sandstone with subconchoidal fracture and coarse quartz grit. Ferruginous, marine-fossil zones occur in the higher parts.

In the Gascoyne Valley and farther north the Callytharra limestone is overlain conformably by about 150 feet of sandstone, certainly of Wooramel type. This sandstone, overlain, in turn, by sandy carbonaceous shale, gives a well defined upper limit. However, those carbonaceous shaly beds, themselves, are locally overlain by sandstones not very different lithologically from those below; hence, no exact correlation with the Wooramel River occurrences can be made on this basis.

To anticipate somewhat, the formation is found to be much thinner in the Gascoyne-Minilya River area than in the type area, and the overlying Byro formation to be much thicker. Field work between the Wooramel and Gascoyne rivers is necessary for determining whether this is due to actual differences in thickness or in grouping.

Only a few poorly preserved fossils were observed. Chapman's determinations of Rudd's specimens from the Wooramel River area are as follows.

Polypora ampla
Fenestella sp.
Strophalosia clarkei
Productus cf. *undatus*
Productus brachythaerus
Taeniothaerus subquadratus
Spirifer hardmani
Spirifer convolutus
Spirifer marcoui
Spirifer musakheylensis var. *australis*
Aviculopecten sprenti
Palaearca cf. *costellata*
Cardiomorpha blatchfordi

Byro formation.—On Byro Station,[5] Wooramel River, thin-bedded calcareous sandstones overlie the Wooramel sandstone and these Rudd named the Byro formation. They represent the highest Permo-Carboniferous beds noted in this valley.

They are described as a series of sandy limestones and calcareous sandstones containing abundant fossil remains. The outcrops commonly show considerable pyrite, marcasite, and gypsum. The thickness is approximately 600 feet.

On the Gascoyne, and farther north, there is a considerable thickness of strata above the equivalents of the Byro beds; hence, the upper limit of the formation requires definition. The Byro beds are overlain by the sandstones forming the Kennedy Range, those sandstones being a well defined lithological group standing out topographically from the underlying Byro beds, so that their base may be taken as a convenient limit of the Byro.

On Gascoyne River the Byro-Kennedy contact is faulted and along the western face of the Kennedy Range the contact relationships are not clear, probably due also to faulting. Along the east face of the range, however, the contact appears to be normal. This was examined on Merlingleigh Station and again on the south side of Minilya River. On Lyndon River it is not exposed, being overlapped by Cretaceous.

The lower limit of the Byro is well defined by the carbonaceous beds resting on the Wooramel sandstone. It is surmised that this contact is disconformable.

On Lyndon River the Byro outcrop is largely obscured by overlapping Cretaceous and deposits of sand, but the lower carbonaceous sandy shales with calcareous concretions appear in the neighborhood of A.26 on Mia Mia Station. A number of drill holes which have penetrated these beds give good sections.

Byro beds crop out along the Minilya Valley from the Williambury-Middalya boundary (Rabbit Proof Fence) to Coolkilya Pool on

[5] The term "Station" as used in Australia designates a large pastoral holding.

Wandagee Station, a distance of about 40 miles. The outcrops are mostly poor throughout since the non-resistant beds erode to low ground, but on Wandagee Station there are good exposures of dark to carbonaceous sandy shales, sandy mudstones with calcareous lenses and, near the top of the formation, thin-bedded sandstones. South of the river also, from Middalya toward Hill Springs, the upper beds are exposed intermittently, showing fossiliferous, calcareous sandstones interbedded with dark shales.

Byro beds also appear along the valley of the Gascoyne from L.9 on Jimba Jimba Station, upstream to a point above the Arthur and Wyndham junctions. North of the Gascoyne the known outcrops form a wedge-shaped area pointing northward, constituting the valley of the lower Lyons River for a distance of about 20 miles above its junction with the Gascoyne. The boundary of this wedge on the west is the base of the Kennedy Range.

The following is a composite section from measurements by Raggatt on the Gascoyne and lower Wyndham rivers.

COMPOSITE SECTION OF BYRO FORMATION ON GASCOYNE AND WYNDHAM RIVERS (DESCENDING ORDER)

	Thickness in Feet
Kennedy sandstone	
a. Mainly clay shale with sandy, mottled shale and some shaly sandstone; *Chonetes pratti* abundant	400
b. Sandy mudstone with richly fossiliferous, calcareous zones, argillaceous sandstone and dark sandy shales; *Spirifer byroensis* common	560
c. Thin-bedded (and current bedded), micaceous sandstone, reddish brown to green alternating with sandy, micaceous to carbonaceous shale; sandy concretions 1–2 inches in diameter and *Deltopecten* aff. *subquinquelineatus* common; *Tribrachiocrinus* sp. abundant at Gascoyne Junction	560
d. Shaly mudstone and dark shale with few fossils; possibly partly freshwater	250
e. Fine- to medium-grained friable white sandstone, thin-bedded; no fossils observed	125
f. Thin-bedded shaly and platy sandstone with dark to sandy shale; poor outcrop	125
g. Flaggy, pitted limestone and calcareous sandstone in alternating beds 5–10 feet thick; small glacial erratics at top	265
h. Highly carbonaceous sandy shale	15
Wooramel sandstone	
	2,300

Group *a* contains beds examined in thin section by Chapman and described as "carbonaceous shales with probable plant remains." The beds of horizon *b* in the Gascoyne River section closely resemble those at Middle Camp on the Wooramel. They contain *Spirifer byroensis* in abundance. The "Jimba Jimba" sandstones *c* are distinguished from any other considerable member in the Permo-Carboniferous by their paper-thin bedding, spherical sandy concretions, and abundance

of *Deltopecten subquinquelineatus*. They are highly micaceous and brown to green in color. Crinoid calyxes (*Tribrachiocrinus* sp.) were found well preserved in large numbers in outcrops of these beds in the river at Gascoyne Junction. The friable white sandstone *e* has been observed only at the one locality, namely, the V-shaped area between the Wyndham and Arthur rivers. These sandstones contain numerous small calcareous concretionary bodies $\frac{1}{4}$ inch in diameter. The carbonaceous shale *h* is useful in defining the base of the formation. On Wyndham River this bed is as highly carbonaceous as to be almost a coal.

FIG. 6.—Carbonaceous shale of Byro formation at Wandagee Homestead, Minilya River

The Byro beds as exposed on Minilya River are divisible into two parts, an upper consisting of mudstone, sandstone and shale, and a lower, largely of dark to carbonaceous shale, and shaly sandstone in which *Chonetes* sp. occur in large numbers. The lower beds which were first noted by Maitland (2) were traversed between Wandagee Homestead and Coolkilya Pool. They are gently folded and disturbed by small faults, and as there are some stretches of the river where there are no outcrops, it is advisable to take the log of the Wandagee No. 1 well (Fig. 2, well location 34) for this part.

The following is a section of the upper portion of the Bryo formation measured by Raggatt along Minilya River, on Wandagee Station.

SECTION ILLUSTRATING UPPER PART OF BYRO BEDS ON MINILYA RIVER
(DESCENDING ORDER)

	Thickness in Feet
Sandy shale	50+
Highly argillaceous sandstone and sandy shale with thin-bedded sandstone	40
Gypseous shale	25
Highly argillaceous sandstone to sandy shale with thin-bedded sandstone	15
Thin-bedded sandstone, current bedded and with sandy shale	110
Thin-bedded sandstone	110
Sandy shale with ferruginous concretions and lenses of very thin-bedded sandstone	60
Thin-bedded sandstone and very argillaceous sandstone	150
Shale, sandy toward the top	70
Thin-bedded sandstone and sandy mudstone with calcareous lenses	130
Thin-bedded sandstone and argillaceous sandstone	40
Carbonaceous sandy shale	50
Massive sandy mudstone with large lenses of hard calcareous sandstone (Cundlego rocks)	130
Thin-bedded sandstone and carbonaceous shale	65
Sandy mudstone with large lenses of calcareous sandstone	110
	1,155

STRATA PENETRATED IN WANDAGEE NO. 1 (FIG. 2, WELL LOCATION 34),
LOWER HALF OF BYRO BEDS

	Thickness in Feet
Dark blue shale with bands of sandstone	728
Hard sandstone	3
Dark blue shale with hard bands	86
Hard sandstone with thin bands of shale	69
"Slate" (probably well bedded hard shale)	164
Black shale with hard sandstone bands	65
Gray sandstone with small bands of shale	20
Hard gray sandstone	25
Black shale with hard bands	9
Hard gray sandstone	7
Sandstone and white quartz	6
Black shale with hard bands	9
Sandstone with white quartz (Wooramel sandstone?)	24
	1,215

Even allowing for the fact that some of the lower beds listed as Byro may prove to belong in the Wooramel, the Byro formation shows a northward thickening as compared with the type area. From Gascoyne River northward the thickness may be fairly constant.

The proportion of shaly beds in the Gascoyne Valley section is greater than in the Wooramel, and this tendency becomes more marked still farther north; north of Lyndon River, sandstones are present only as very thin beds.

The Byro formation is characterized by a number of rich, fossiliferous zones separated by barren or sparsely fossiliferous strata. Illustrative of the former are the Jimba Jimba sandstones with abundant *Deltopecten subquinquelineatus* McCoy and *Tribrachiocrinus* sp., the sandy limestones near the top with *Linoproductus tenuistriatus* found on Middalya Station, the *Spirifer byroensis* calcareous sand-

stones on the Gascoyne and the recurring thin beds crowded with *Chonetes pratti* and *Chonetes hardrensis* on the Minilya and Gascoyne rivers.

Clapp (4, page 55) collected fossils from Byro beds, 5 miles west of Gascoyne Junction, which were identified by the late W. S. Dun as *Productus bellus* (*Linoproductus concriniformis*), *Spirifer* cf. *lata* (Eth. and Foord not McCoy, will be renamed *maitlandi*), *Plerophyllum australe* Hinde, and *Chonetes* sp. (*pratti?*). Clapp also collected *Spirifer* cf. *musakheylensis* and *S. marcoui* from beds fairly high in the Byro on the east side of the Kennedy Range near Merlingleigh.

Kennedy sandstone.—Every observer in the region has commented on that marked topographic feature, the Kennedy Range—a deeply dissected, approximately flat-topped block, rising 300–400 feet above the surrounding country (1,200 feet above sea-level), composed almost entirely of sandstone, and extending from the Gascoyne to Minilya River, a distance of 65 miles. This block was examined at intervals around its margin and the fact established that the sandstones composing the range overlie the more shaly strata of the Byro formation, the contact being conformable. These sandstones are named the Kennedy.

It may be mentioned here that the alignment of the Moogooloo, Kennedy, and Carrandibby ranges has suggested to some observers (5, 6) a more or less continuous line of outcrop of the same formation, but Rudd found the Carrandibby Range to be composed of pre-Cambrian rocks, and the Moogooloo Range, as already stated, consists of Callytharra limestone and Wooramel sandstone, more or less brought into line with the Kennedy Range by faulting.

The nearly flat top of the Kennedy Range is an erosion surface and nowhere on it do any higher Permo-Carboniferous rocks appear to be preserved. Structurally the mass is a broad asymmetric syncline with a short, steep west limb. Sand hills are found on the top on Merlingleigh Station (first recorded by Clapp 4). J. Thompson of this station has picked up several internal casts of a shell identified by Chapman as *Aturia* sp. (Eocene to Miocene) from a locality 2 miles northeast of the shearing shed. These suggest possible former eastward extension of Tertiary beds.

Maitland (2) commented on the lithological resemblance of the rocks of Wandagee Hill to the Kennedy Range sandstones, and there is little doubt that they belong to the same formation. At Wandagee Hill the conformable contact with the Byro beds is well shown. Here again, however, there is no evidence of the existence of higher Permo-Carboniferous beds since Cretaceous shales (belemnite-bearing) overlap the Kennedy beds.

At Coolkilya Pool on Minilya River, 7 miles north of Wandagee Hill, however, is a section showing Byro beds passing upward into sandstones, these in turn being overlain conformably by a considerable thickness of shale with rather distinctive Permo-Carboniferous fossils. Though these sandstones can not be followed continuously to Wandagee Hill, some of the underlying Byro beds can be traced in such a way as to confirm the identity of the sandstone at Coolkilya with that at Wandagee Hill, and a further valuable check is afforded by Wandagee No. 1 (Fig. 2, well location 34), 1½ miles northwest of the hill, put down almost wholly in Byro beds. Thus, the fact is established that there is a considerable thickness of Permo-Carboniferous strata, largely shaly, overlying the Kennedy sandstone.

South of the Gascoyne, outcrops of the Kennedy sandstone have not been observed in outcrop, but Rudd provisionally assigned 800 feet of sandstone encountered in a deep well drilled on Bryo Station to a stratigraphical position above the Byro beds.

The Kennedy sandstone forms one of the most important aquifers in the Northwest Artesian Basin and can be readily identified in a number of deep wells put down in the coastal region, west and northwest of the outcrop.

Since the top of the Kennedy Range is an erosion surface, most of the formational sections are incomplete, and the logs of the bores in the lower Gascoyne Valley furnish the best data. However, a number of sections were measured by Raggatt around the margins of the range, one being as follows.

INCOMPLETE SECTION, KENNEDY SANDSTONE, 10 MILES SOUTHWEST OF K.54

	Thickness in Feet
Hard, flaggy, micaceous sandstone	125+
Hard ferruginous sandstone	3
Soft argillaceous gray sandstone with abundant spherical ferruginous concretions and platy ferruginous bands; *Spirifer byroensis*, *S. musakheylensis*, and *Cardiomorpha blatchfordi*	125
Ferruginous flaggy sandstone	50
	303+

The thickness at Wandagee Hill is 350 feet. Near the top are numerous poorly preserved fossils including *Aviculopecten tenuicollis* and *Spirifer*.

A section exposed at Coolkilya Pool, on Minilya River shows a thickness of 503 feet with 39 feet of shales and 90 feet of shaly sandstone a little above the middle. The shaly nature of this section suggests that identification of the formation in logs of wells farther north might be difficult.

Data from a few well logs follow. Boolathanna No. 6 (Fig. 2, well location 47) and Pelican Hill (Fig. 2, well location 52) proved 660 feet of Kennedy sandstone, and Brickhouse No. 1 (Fig. 2, well location 54) 700 feet. These beds were encountered in the last named from 1,933 feet to the bottom, giving a thickness of 701 feet.

Fossils are not abundant in the Kennedy sandstone, but occasional ferruginous bands contain large numbers of a few species such as those recorded by Maitland (6, page 34) from the top of the south end of the Kennedy Range: *Spirifer* sp., *Productus* sp., and *Strophalosia* sp.

Strophalosia clarkei and *Aviculopecten tenuicollis* (identified by H. O. Fletcher) occur fairly abundantly in the basal yellowish-brown sandstone on the west side of the range, 2½ miles southsouthwest of Mooka Spring. From ferruginous beds near the base, at a point 10 miles southwest of K.34, Chapman identifies: *Spirifer byroensis* Glauert, *S. musakheylensis* Dav., *Spirifer musakheylensis* var. *australis* Foord, and *Cardiomorpha blatchfordi* Hosking. These forms are also found in the Wooramel sandstone, 2,300 feet stratigraphically below the Kennedy sandstone.

Wandagee formation.—One of the most interesting results of the investigations was the discovery by Raggatt of a considerable thickness of shaly strata above the Kennedy sandstone, here named the Wandagee from a station of that name on Minilya River.

Downstream from Coolkilya Pool on Minilya River are excellent exposures of these shales and shaly sandstones containing *Chonetes*, *Aulosteges*, and *Spirifer*. The beds rest conformably on the Kennedy sandstone, and are overlain by fossiliferous, marine Cretaceous.

With the aid of logs of artesian and sub-artesian wells spaced from Wandagee Station to Minilya Station, and thence north and south in the deeper part of the basin, it is possible to trace the Wandagee beds under cover and confirm the lithology. Although little is seen of the Wandagee in outcrop, there is good evidence that the formation formerly extended over a considerable area in the Northwest Basin.

Minilya River downstream from Coolkilya Pool provides the type section (measured by Raggatt).

INCOMPLETE SECTION OF WANDAGEE FORMATION ON MINILYA RIVER, STRATA IN DESCENDING ORDER

	Thickness in Feet
Shale, carbonaceous and sandy with thin beds of finely laminated sandstone; more sandy near top; marine fossils	385+
Argillaceous sandstone and soft sandy mudstone with calcareous and ferruginous, concretionary zones. *Aulosteges ingens* and *Spirifer rostalinus* var. *crassa*, common; *Chonetes pratti*, *Spirifer marcoui*	385
Clay-shales with calcareous and ferruginous concretions, dark near the base.	500
	1,270+

The Pelican Hill (Fig. 2, well location 52) passed from glauconite sands at the base of the Cretaceous into the Wandagee beds at a depth of 1,406 feet and continued in them to 2,350 feet. The following section is compiled from an examination of the cores and of notes from office files made available by F. Forman, Government geologist. The fossils were determined by R. Etheridge, Jr.

SECTION OF WANDAGEE BEDS IN PELICAN HILL WELL

	Thickness in Feet
Shaly limestone with *Aviculopecten* sp.; *Spirifer* sp.	32
Gray to green hard shale	8
Mainly fossiliferous limestone with thin shale bands	50
Dark gray shale and crystalline, fossiliferous limestone	150
Fossiliferous, crystalline dark gray limestone	50
Hard, dark green clay shales	315
Calcareous sandstone	50
Green and gray shale with sandy bands	85
Calcareous sandstone	30
Green to gray compact, clay shale with bivalves and small dendroid coral probably *Monticulipora*	130
Hard siliceous gray shale	43
	943

Boolathanna No. 6 (Fig. 2, well location 47) also proved a section of these beds between the depths of 1,472 and 2,920 feet (about 1,450 feet in thickness), the upper portion including limestone. It is of interest to note that below the depth of 2,095 feet the drill passed through three feet of quartz, possibly a glacial erratic.

The following fossils, identified by Chapman, are all very abundant at the type locality, Wandagee Station on Minilya River, downstream from Coolkilya Pool: *Chonetes pratti* Dav., *Stenopora* sp., *Spirifer convolutus* Phil., *S. rostalinus* var. *crassa* Hosking, and *Taeniothaerus subquadratus*. Beautifully preserved specimens of *Aulosteges ingens* and *Spirifer marcoui* (identified by H. O. Fletcher) also are common.

CORRELATION OF IRWIN RIVER FORMATIONS WITH NORTHWEST BASIN SECTION

The exposures on Irwin River were first described by Campbell (11) and later by Woolnough and Somerville (9). Detailed sections, measured by Raggatt, are given in the following condensed form.

SUMMARY OF IRWIN RIVER EXPOSURES

	Thickness in Feet
Shale, largely carbonaceous and with glacial erratics (marine)	300
Shale, sandstone and coal seams (fresh water)	250
Highly fossiliferous (marine), calcareous mudstone to shaly limestone	75
Shale with some sandy mudstone, calcareous concretions (Contains *Metalegoceras jacksoni* cephalopod horizon)	1520
Glacial beds and shales	—

Any field worker proceeding from Irwin River to the Wooramel, thence to the Gascoyne and northward must be impressed with the general similarities in the Permo-Carboniferous succession. In all localities the basal part denotes glacial conditions in neighboring land areas extending over a long period of time. Higher in the section, glacial phenomena become less in evidence, the sandstones with boulder horizons being succeeded by extensive fossiliferous, calcareous shaly beds, these in turn giving way to richly fossiliferous limestones and calcareous mudstones which, in the northernmost exposures, attain a thickness of more than 450 feet. Thus, the evidence denotes geological environments much more than local, which must have prevailed over areas even more extensive than Western Australia.

The case for regional correlation of the glacial beds has been well stated by Maitland (3), and the fact now realized that these water-lain beds exceed 2,000 feet in thickness in the northwest strengthens the argument. In fact, the Lyons beds are continuous from Lyndon River to the Wooramel, a distance of 150 miles , and have been found by Maitland still farther south on the Murchison, intermediate between the Wooramel and the Irwin rivers, the occurrences thus denoting glacial conditions on a grand scale.

Correlation of the glacial beds carries with it the almost inevitable corollary that the Fossil Cliff horizon of Irwin River is the stratigraphic equivalent of the Callytharra limestone. The beds are strikingly similar and have many fossil species in common. On the latter evidence Lucy Hosking suggested a correlation between the beds at Callytharra Spring and Fossil Cliff (12, 13).

Apparently this conclusion is not supported by Chapman who refers the Callytharra fauna to the Upper Carboniferous and the Fossil Cliff beds to the Lower Permian (15). He also states that the foraminiferal fauna of the Fossil Cliff beds includes many species in common with both the Pennsylvanian and Permian of Texas (Upper Carboniferous to Middle Permian). This statement does not preclude the possibility of correlating the Callytharra and Fossil Cliff beds. David placed the Fossil Cliff beds in the Lower Permian (7), but did not refer to any Northwest Basin horizons other than the Lyons glacials.

The general nature of the sedimentation above the Fossil Cliff horizon on Irwin River and above the Callytharra stage in the Northwest Division suggests that the Wooramel and Byro formations are represented on the Irwin, and that the still higher Kennedy and Wandagee formations, either were not deposited in the south or else were subsequently eroded away prior to deposition of the Jurassic. Correlations suggested are summarized in Table II.

TABLE II

CORRELATION OF PERMO-CARBONIFEROUS OF IRWIN RIVER AND NORTHWEST BASIN

Irwin River			*Northwest Basin*			
Unit (After Woolnough and Somerville)	*Lithologic Characters*	*Thickness in Feet*	*Unit*	*Lithologic Characters*	*Thickness in Feet*	
					Wooramel River	*Gascoyne and Lyndon Rivers*
			Wandagee	Shale, shaly sandstone and limestone, erratics	Not present	1,250–1,800
			Kennedy	Sandstone	800? in bore	500– 700
				(a) Argillaceous sandstone mudstone and shale		(a) 960–1,160
Upper Marine	Gray to carbonaceous shale with erratics	300	Byro	(b) Carbonaceous and sandy shale with thin sandstone and limestone beds, erratics	600	(b) 1,200–1,440
Coal Measures	(a) Shale and coal seams	50		(c) Highly carbonaceous shale at base	—	(c) 10– 15
	(b) Mainly sandstone	200	Wooramel	Sandstone	800	130– 280
Fossil Cliff beds	Calcareous shales and limestone	75	Callytharra	Flaggy limestone and calcareous shale	85	200– 460
Olive shales Cephalopod horizon Buff beds Bull Paddock limestone Gray limestone Spheroidal marls	Shale and mudstone with thin calcareous beds	1,520	Lyons	(a) Shale with thin calcareous beds	500	(a) 170– 380
Glacial beds Sub-glacial beds Basal grits Boulder clays	Grits and clays with boulder beds and erratics	?	Lyons	(b) Sandstone and boulder beds and erratics; some shale		(b) 1,750–2,100

CRETACEOUS STRATIGRAPHY

One of the surprising results of the recent work has been the recognition of the Cretaceous age of the rocks covering the area formerly indicated as Jurassic and also the Cretaceous age of much of the area represented as Permo-Carboniferous on the geological map of Western Australia. It is estimated that 60 per cent of the area north

TABLE III

GENERALIZED SECTION OF WINNING AND CARDABIA SERIES AT TYPE LOCALITIES

Miocene -Eocene	*Location*	*Foraminiferal Dense Limestone*	*Thickness in Feet*
Cardabia series (1,070 feet)	Near Remarkable Hill, Cardabia Station	Sandy, white to yellow, polyzoal limestone with hard, yellowish green bands up to 10 feet in thickness	85
		Glauconite sand to sandstone with *Ammonites* and coprolites	5
		Shaly marls, with platy shell fragments of *Inoceramus* throughout	115
		Gypseous green and gray clay shales	30
		Chalk with spherulitic barite concretions, 2–3 inches in diameter	—
	Maud Landing bore	Mainly chalk, with chalky clays and calcareous claystones	835
Winning series (1,100 feet)	Windalia Hill (A. 46), Winning Station	Coarse grit	1
		White to pink chert	3
		White, yellow, pink, and brown, punky, light-weight siltstone with small flakes of white mica	55
		Yellow, green, and buff sandy siltstones	40
		Gray shaly rock; slightly slick in water and breaks into small pieces	10
		Bright yellow sand with *Ammonites*	1+
	Winning No. 1 well	Mainly dark gray to greenish gray mudstones with some fine green sands*	784
		Green shale	40
		Gray mudstone	145
		Green shale (commonly seen also in outcrop)	20
		Sand (commonly seen also in outcrop)	3

* Drilling in progress in this formation during field work.

of Murchison River and west of Longitude 115° consists of, or is underlain at shallow depths by, strata of Cretaceous age.

The Cretaceous is divisible into: (a) a lower series of radiolarian cherts, white and vari-colored silts, and glauconitic sandstones, now named the Winning formation (or series); and (b) an upper series of limestones, chalks, shales, and glauconite sand designated as the Cardabia series.

A complete stratigraphic section of the Cretaceous compiled from surface measurements is not available. Probably most of the units comprising the Winning series are to be seen in outcrop but the mesas in which these occur are widely scattered and with such gentle dips that detailed measurements have not been attempted. Thicknesses of 100–150 feet are exposed in many widely separated localities.

Only the top 100–300 feet of the Cardabia series has been studied in outcrop. The lower part has been proved in a number of wells from some of which core samples are available. These have been examined lithologically and paleontologically. Mapping of the outcrop geology in the vicinity of a number of other wells has established relationships.

WINNING SERIES

The series is named after the locality, Winning Pool (Winning Station), about midway between Carnarvon and Onslow. It is the oldest Cretaceous known in the region and has the widest distribution. Outcrops extend from Minderoo Station, on Ashburton River, south to Gascoyne River, a distance of nearly 200 miles, overlapping both Permo-Carboniferous and pre-Cambrian. The formation has not been recognized in outcrop more than a few miles south of the Gascoyne, but has been identified in wells on Woodleigh Station, about 40 miles east of Hamelin Pool.

Most wells in the coastal region north of Wooramel River penetrated the Winning series, the basal sand being one of the most important aquifers of the entire artesian basin.

It is doubtful whether the thickness of the series can be measured accurately from outcrops. The thickness proved by Pelican Hill (Fig. 2, well location 52) is 300 feet, Brickhouse No. 1 (Fig. 2, well location 54) 350 feet, and Grierson's Tank (Fig. 2, well location 38) 450 feet. Identification of the series in the wells, based on lithology of the samples and study of the micro-fauna by Chapman and Crespin, shows good agreement. The various well-log data indicate thickening of the series from south to north.

Except for the abundance of the belemnite *Dimitobelus diptychus* in the green shales of this series, macroscopic fossils are comparatively scarce, and in most instances are too poorly preserved for specific determination. The following are the only genera recognized with certainty by F. W. Whitehouse: *Syncyclonema*, *Trigonia*, *Thracia*, *Maccoyella*, and *Barbatia*. The rocks in the upper part of the sequence are, however, rich in *Radiolaria*. According to Chapman the most common forms present are *Lithocyclia exidis*, *Dictyomitra australis*, and

Stichocapsa. Diatoms have been recognized by Miss K. Prendergast.[6]

Whitehouse suggests that the belemnite beds may be regarded tentatively as equivalents of the Tambo series (Albian) of Queensland. Chapman considers that the radiolarian rocks are practically identical with those from Fanny Bay (Darwin) and, therefore, should be placed in the Upper Albian. His remarks apply both to specimens collected from widely separated localities and to core samples from the Pelican Hill well.

The upper limit of the Winning series is readily recognized in well logs by the change from foraminiferal chalks (Cardabia series) to darker shaly beds with nodules of pyrites passing downward into radiolarian mudstones, silts and cherts. No attempt has been made to trace these changes in outcrop. Well-log correlations suggest that the contact is regular and that there was no interformational folding.

CARDABIA SERIES

Exposures of these, the highest Cretaceous beds, are largely confined to the eastern scarp of the Giralia-Cardabia Range. K. Washington Gray and Raggatt propose the name Cardabia after the station of that name where there are many good outcrops.

The Cardabia beds are readily recognizable, both in outcrop and well cuttings. They consist predominantly of white chalks, chalky mudstones, and marls, commonly with abundant fragments of *Inoceramus* shell and *Foraminifera*. The highest beds vary from hard to soft, yellowish green, polyzoal limestone to glauconitic, calcareous sandstone. A glauconite sand occurring commonly between these two principal lithological divisions commonly contains abundant *Ammonites*.

The *Inoceramus* marls merit special comment. In some places the aragonite fragments are so abundant as to compose the greater part of the strata and one might almost question their organic origin. Fragments of shell with thicknesses up to 0.8 inch have been collected. There is a tendency for the fragments to occur in nests with many individual pieces inclined to the bedding of the marls. Evidently these shells have been worked over to some extent and stratified. Pieces of redeposited *Inoceramus* also are common in the Tertiary limestones adjacent to areas of outcrop of the Cretaceous.

There follows a section of part of the Cardabia series based on examination of samples from the Pelican Hill well (Fig. 2, well location 52) between the depths of 250 and 1,105 feet, and compiled from core data.

[6] Oral communication.

CARDABIA SERIES IN PELICAN HILL WELL

	Thickness in Feet
Gray chalky claystone	30+
Chalk	170
Calcareous greenish gray claystone	150
White chalk	440
White to gray compact chalk and chalky clay	65
	855+

This well is 80 miles south from the nearest exposure of the highest Cardabia beds. There is nothing in the driller's terms or in the samples preserved to suggest the presence of the ammonite greensand

FIG. 7.—Middalya Station; relief 150 feet; well bedded white siltstones and cherty shale below and chert cap at top.

or the polyzoal limestone. Chapman identifies *Inoceramus* prisms in the whole sequence. As similar remarks apply to the other wells in the lower Gascoyne it is possible that the highest beds either were not deposited there or were removed in early Tertiary time, the former suggestion being the more probable.

Well data suggest that the Cardabia series maintains a fairly uniform thickness over the greater part of 130 miles from Gascoyne River north to Cardabia Station, but with perhaps 200 feet thickening in that distance assuming that the uppermost beds were not deposited on the lower Gascoyne.

The upper part of the Cardabia contains a number of macroscopic

fossils including *Ammonites*, and the series as a whole is rich in *Foraminifera*.

An ammonite greensand near the top of the series has been observed and collections made in localities spaced over a distance of 50 miles. Field work and paleontology prove the same horizon is represented from place to place. Immediately above the ammonite bed in several places is a bed with lamellibranchs, brachiopods, and gastropods most of which are not well preserved.

The macro-fossils from the greensand have been determined by Whitehouse who supplied the following notes after a preliminary examination. He states that many additional genera are present and that the age is Campanian.

FOSSILS FROM GREENSAND HORIZON

Eubaculites aff. *vagina* Forbes
Parapachydiscus sp. cf. *compressus* Spath
Gunnarites kalika Stoliczka
cf. *Pseudophyllites indra*
Phylloceras cf. *forbesianum* (d'Orb)
Schluetheria aff. *simplex* Hoepen
Schluetheria aff. *rousseli* Grossoeuvre

Beds immediately above the greensand yield *Ostrea vesicularis* Lamarck; *Cyclothyris* cf. *plicatiloides* Stoliczka; *Pleurotomaria* sp.

Chapman and Crespin have examined much material from outcrops and wells, and have determined a large number of micro-fossils. It is impossible to do justice to their work in a summarized account and it is hoped that details will be published. For the most part, their determinations suggest that the Santonian-Cenomanian interval is represented in the collections from beds below the ammonite greensand.

As a whole they consider the marls and chalks to be referable to the Turonian stage of the Upper Cretaceous, and that possibly beds as low as Cenomanian are also present. Thus, it appears that a fairly complete record of the Cretaceous is present in the Northwest Basin.

TABLE IV
AGE DETERMINATIONS

Cardabia series	Polyzoal limestone	
	Ammonite greensand	Campanian
	Inoceramus marls, Chalks, chalky clays and claystones	Santonian-Turonian, Cenomanian (?)
Winning series	Siltstones, cherts, shales, and glauconitic sands	Albian

In the northernmost exposures the Cardabia passes upward into the Eocene, but near Salt Lake into limestones tentatively referred to the Lower to Middle Miocene. The conditions, therefore, are those of overlap. When the paleontologic studies have been carried farther

they may show that the Cretaceous underwent slight erosion in the south during deposition of the older Tertiary elsewhere.

The Cretaceous and Tertiary have been folded to much the same extent on the Giralia anticline; well data in the coastal region clearly reveal that folds are approximately equally developed from the base of the Cretaceous at least to the Miocene, though the presence of redeposited *Inoceramus* debris in Tertiary limestones shows there was some late Cretaceous warping.

TERTIARY STRATIGRAPHY

Much remains to be done before the Tertiary beds can be properly described. In the main, the area of deposition of the Tertiary (consisting almost wholly of limestones) seems to have approximated fairly closely that of the Cardabia series as developed northward from Carnarvon. Southward from Carnarvon, wells pass directly from post-Tertiary into Upper Cretaceous. The Tertiary beds reach their maximum development in the Northwest Cape Range where horizons possibly as low as Oligocene are exposed.

The lowest beds in the region are those containing *Discocyclina* and *Nummulites* which Chapman and Crespin refer to the Middle to Upper Eocene (15). These rest on the Cardabia series as seen in the Giralia anticline.[7] They appear to be a very thin formation and their relationship to the higher Tertiary is unknown.

Limestones with a great abundance of *Lepidocyclina* attain a thickness of 550 feet in the section exposed on the eastern side of the Cape Range. Their age is Lower Miocene possibly ranging down to Upper Oligocene. Overlying these in the same area is a marine, white foraminiferal limestone about 60 feet thick, also Lower Miocene. Still higher are well bedded white limestones 100 feet thick, the age of which is undetermined but which possibly may be correlated with the Mio-Pliocene coralline limestones forming the western side of the range.

The coralline limestones on the western side of the range are overlain by cemented and travertinized sands interbedded with which are thin lenticular foraminiferal limestones. These sands are, at least in part, travertinized dunes and bear the same relationship to the Mio-Pliocene limestones as do the sands which are being deposited at present in lagoonal waters between the beach and the fringing reef. Some of the cemented sands are coarser than the modern beach sands, but closely resemble the sands which form the surface of large areas such as between Giralia and Winning stations. Small quartz pebbles and

[7] This fossil locality, discovered by Condit and Rudd, is the only known occurrence of marine Eocene in Australia.

layers of coarse grit are commonly found near the base of the cemented sands.

It is of interest to refer to specimens of Tertiary fossils found near Merlingleigh Homestead by J. Thompson, namely ironstone casts of a marine fossil identified by Chapman as *Aturia*. It is quite possible they have been derived from the disintegration almost ***in situ*** of a Tertiary (Eocene-Miocene) deposit. This locality is about 90 miles inland from known Tertiary rock occurrences.

POST-TERTIARY

The younger beds include shelly beach deposits, oölitic limestones, sands, travertine, and coral reef rocks of Pleistocene to Recent age. These beds are well developed as a belt 2–5 miles wide, extending inland from the coast between Onslow and Cape Locker. Their appearance and attitude suggest having been warped into gentle folds with axes parallel with the coast. They are much obscured by sand dunes and clay pans.

Coquina beds are well developed around Salt Lake and the lower Wooramel Valley probably not more than 20 feet above sea-level. Travertine deposits containing shell fragments were observed at intervals from Giralia Station to Yalobia. They cover extensive areas overlain here and there by sand ridges. The disposition of the outcrops suggests that they form (or formed) a broad belt sub-parallel with the present coastline.

Chapman describes a specimen from Mia Mia No. 1 Woolshed well (Fig. 2, well location 12) as "a fragmental travertine limestone probably deposited near the strand line. The detrital portion consists of angular quartz grains, shell fragments, occasional obscure *Foraminifera* and a few oölitic grains."

Sand hills are extensive in certain areas notably between Northwest Cape and Ashburton River and west of the Cardabia-Giralia Range. A number of sand ridges were noted between the Minilya and Lyndon rivers. These occur between low hills of Permo-Carboniferous rocks which they parallel. They carry scrubby vegetation or are thickly covered with spinnifex (a grass). The fact that large areas of sand hills are fixed by vegetation suggests climatic amelioration in late times.

STRUCTURE

The purpose of this paper is primarily stratigraphic description; therefore, observations as to structure are set forth only briefly. Structurally, the region forms the east limb of a synclinorial basin of late

Paleozoic to Recent sediments, underlain by pre-Cambrian basement rocks. There are many reversals from the regional westerly dip, particularly in the more easterly part of the region. Folding is more or less general over the entire area of Permo-Carboniferous rocks, and the well record correlations show that this condition persists westward under cover but is less accentuated in that direction.

STRUCTURE IN PERMO-CARBONIFEROUS OUTCROP AREA

A comparatively narrow disturbed area trending about N. 15° W. persists for 135 miles from Arthur River almost to the Lyndon near Moogooloo Peak. At the south end this is anticlinal, the outcropping limbs, as defined by the Callytharra limestone, being 7–8 miles apart. This structure is bordered on the east by a fairly sharp syncline, the axis trending N. 15° W. through K.34. Though folds are still in evidence from Lyons River northward, a number of normal faults appear, with strikes paralleling the axes of folding. Chief of these are the Moogooree faults which extend at least from near Mount Sandiman shearing shed to K.51 on Lyndon River, a distance of 40 miles. The fault blocks form a series of steps; the amount of throw on the main fault near Moogooree is about 500 feet.

North of Williambury Homestead and between Williambury and Middalya, the strata are much disturbed; the Callytharra-Wooramel sequence is repeated several times by gentle folds and strike faults giving rise to parallel ridges, such as those at Moogooloo and K.34, trending N. 15° W. Here also are faults striking N. 75° W., probably minor features, but the general westward offsetting of the beds and structure north of the Lyndon, as compared with conditions south of it, suggest a major fault trending N. 75° W. and with downthrow on the south.

The Kennedy Range is a synclinal and possibly closed basin structure. Along the eastern edge, the beds have gentle westerly dips; along the western edge they have high (30°–55°) easterly dips; and at the north end, southerly dips, thus giving an asymmetric profile with the synclinal axis near the western margin. This structure shows an interesting influence on water supply.

STRUCTURES IN CRETACEOUS-TERTIARY OUTCROP AREA

A number of folds, several of them domal, have been observed in the Cretaceous-Tertiary outcrop area. In all examined, the rocks of both systems appear to be folded to nearly the same extent, judging from both outcrops and well data. The axes trend N. 10° E. to N. 25°

E. The structures include Cape Range, Rough Range, and Giralia. The first two being only slightly denuded are expressed topographically as rounded ridges.

The Cape Range anticline forms almost the whole of the peninsula after which it is named. At sea-level it is 100 miles in length and 25 miles in width. Its topographic relief exceeds 1,100 feet and this may be an approximate measure of the amount of structural closure. Dips on the eastern limb are 6°–8° and on the western limb about 2°. Beds ranging from Mio-Pliocene to Lower Miocene age are exposed in the principal deeply cut gorges.

The Rough Range structure borders the southern end of the Cape Range which it parallels. At sea-level it is 23 miles long and 1–3 miles wide, and has a topographic relief of 350 feet. Like the Cape Range, the eastern limb has the steeper slope with dips up to 8° on that flank and perhaps 1°–2° on the west. All the beds exposed are probably Upper Miocene to sub-Recent.

The Giralia anticline extends from near the mouth of Lyndon River to the head of Exmouth Gulf, a distance of 65 miles, and is expressed in an irregular range of hills of the west flank. Near Giralia Station, however, both flanks are clearly defined. Dips are low, not more than 3°, the eastern limb being slightly steeper. Almost all the Tertiary beds have been eroded from the eastern limb, exposing the Cardabia and Winning series.

GEOLOGIC HISTORY

No record of geologic events, from the time of the great granite intrusives of the Mosquito series (pre-Cambrian) until late Paleozoic, exists anywhere here or south as far as Irwin River. Upper Paleozoic sedimentation commenced with the water deposition of glacial debris (Lyons series). All of the pebbles and boulders in these beds can be matched in the Mosquito series and, moreover, granitic types greatly predominate. Thus, early or Middle Paleozoic rocks, if ever deposited, had been completely removed before Carboniferous time from the parts of the basin which can be examined, and the highlands bordering the basin on the east, then being subjected to glaciation, had been worn down to their granite core.

The size and abundance of the boulders in the Lyons boulder beds, many of them 3–4 feet in diameter and well rounded, suggest derivation from a landscape with considerable relief. Though there is no conclusive evidence as to the environment in which the lowest beds were deposited, most of the materials show water sorting and marine fossils are sparingly present in all except the lower part of the se-

quence. Local patches of tillite, appearing in the midst of the water-sorted materials confirm the importance of iceberg rafts.

As time went on the marine glacial deposits accumulated to considerable thickness; the general composition changed from arkosic sands to fine-grained, shaly sandstones, siltstones, and clay shales. Degradation of the granitic range proceeded along with basin filling. A milder climatic cycle led to marked abatement of glaciation with resulting eustatic submergence and shifting of shore lines, and ensuing quiet off-shore conditions favoring deposition of richly fossiliferous calcareous muds of the Callytharra type.

The initiation of deposition of sands of the Wooramel stage following abruptly upon the Callytharra suggests rapid regression of the sea. Shallow water marine conditions were succeeded later by brackish, lagoonal conditions as suggested by the presence of cross-bedding and the passage upward into carbonaceous sediments in the basal part of the Byro formation.

The record subsequent to Wooramel time is one of less abrupt changes. Deposition of carbonaceous shales of the Byro took place at and near sea-level. Prolonged shallow conditions are denoted by shaly limestones, ripple-marked beds, worm tracks, grouping of fossils and diversely directed cross-bedding (as shown by the Jimba Jimba sandstones). Colder climatic conditions in late Byro time are suggested by presence of occasional small ice-rafted erratics in the highest beds. A little later there came a recurrence of conditions resembling those of Wooramel time with deposition of the Kennedy sandstone.

Deposition of sands of the Kennedy terminated through eastward shifting of the shores, again probably eustatic; marine life flourished and considerable thicknesses of shales and calcareous beds were laid down. Small glacial erratics, dropped locally, denote local recurrence or possible persistence of glaciation in the adjacent land areas in late Wandagee time. Thus closes the record of Paleozoic sedimentation.

So far as known, the whole of Triassic and Jurrassic time is unrepresented in the Northwest Basin, but fresh-water Jurassic deposits are found in Irwin River district resting on the Permo-Carboniferous. Some time in the late Paleozoic-Jurassic folding took place. This may have been associated with uplift of the old bordering range since the effects are more pronounced toward the margin of the basin and gentler westward. Unlike the folding in the east during the late Paleozoic, no igneous activity accompanied this diastrophism.

In the Albian epoch the whole region was submerged beneath the sea and much of it remained so until well into the Tertiary. The sea extended far inland and Cretaceous sediments were deposited across

the folded Permo-Carboniferous and the Basement complex. It is surmised that deposition of each successively younger series took place in a sea receding northwestward. The *Aturia* found at Merlingleigh, probably authentic, suggests, however, that the Tertiary sea extended at least 125 miles inland from the present coast.

Obviously no marked structural deformation ensued during Cretaceous and early Tertiary time. The folding on a large scale which produced the Cape Range and lesser warps in the coastal area probably came in Pliocene time. Post-Cretaceous faulting, observed at several places, probably was synchronous with this folding.

The folding which commenced near the end of the Tertiary may be still in progress. Sub-recent deposits near Onslow appear to be gently warped. Well preserved remnants of successive wave-cut terraces ranging from 15 to 180 feet above sea-level, so well exhibited on the west coast of the Cape Range, testify to intermittent emergence.

The history of sedimentation shows that there were two periods of loading in the basin, the Permo-Carboniferous and the Cretaceous-Tertiary and those may have some bearing on the diastrophic movement following each period. With compression from the oceanward side during the earlier period of diastrophism the sedimentary series in the more eastern part, buttressed about the old (pre-Cambrian) massif, gave rise to structures arranged parallel with it. The orientation and position of the younger folds in the coastal area was perhaps largely determined by the older folding, and influenced by pre-existing tectonic lines.

WELL DATA AND RELIABILITY IN CORRELATION

Approximately 80 wells ranging in depth from 400 to 4,013 feet, and most of them from 1,200 to 2,500 feet, have been drilled in a comparatively narrow coastal strip extending from Onslow to the mouth of Wooramel River. Many farther south have not been studied. Most of the wells have been sunk along the lower Wooramel, Gascoyne, Minilya, and Lyndon valleys and very few in the more northern part. There are also a great number of shallower wells.

The well data include logs of many wells most of which were drilled with cable tools, samples of drill cuttings being available in a few instances, and cores from a few deep wells. Considerable effort has been made to gain an idea as to the reliability of the drillers' logs and the meaning of descriptive terms used, as well as to verify formations as logged through comparative studies of outcrops where available in the vicinity of a well. An understanding of drillers' terms was supplemented during recent field work through drilling then in progress.

The commonly mentioned "flint" or "black flint" is a most reliable marker for correlation. This, as earlier anticipated, proves to be the same as the Upper Albian radiolarian chert observed in outcrop. A puzzling feature has been that water is commonly recorded at this horizon, but from interrogation of drillers, it appears that the water is struck immediately below the chert.

Sandstones and greensands are logged with fair accuracy, and pyrites common in the highest Winning black shales is usually correctly designated. The sequence, "flint-green shale-soft sand," is sufficient to distinguish the lowest Cretaceous in most well logs. The sand at the base of the Cretaceous, though commonly only a few feet thick where drilled through, yields large quantities of water of stock quality.

Since the Cretaceous rests on the folded and eroded Permo-Carboniferous throughout this area, recognition of the base of the Cretaceous in wells also marks the point at which the Permo-Carboniferous is entered. Of the 80 or more wells drilled in the area from the Wooramel Valley northward about 49 started in or passed into the Permo-Carboniferous. In these, the formations penetrated can be determined usually by comparing the logs from place to place, working down-dip from those nearest the outcrop. A particularly good group for this purpose includes the Wandagee Nos. 2 and 3 (Fig. 2, well locations 35 and 33) and the Minilya group (Fig. 2, well locations 20 to 29), from which correlations can be carried north and south along the coast.

The terms "shale" and "blackjack" call for special comment. Rudd concluded that such terms as used by station people and drillers in the Wooramel area were quite unreliable. Clapp (5) found that fine-grained material has often been termed "shale" in the northwest region, and stated (page 420), that "only a few feet of shale were actually seen or authentically reported in the basin."

It is true that various fine-grained rocks with partings are commonly logged as shales whether largely argillaceous or not; moreover, some of the aquifers have been termed "shale." It can be stated, however, that the uppermost shale beds of the Permo-Carboniferous succession as well as shales of the Cretaceous have for the most part been described correctly in the drillers' logs, the latter rightly with adjectives such as "green, sticky" prefixed. Where the driller refers to "clay shale," "sticky" or "puggy shale," it is fairly certain he has described the beds correctly.

The name "blackjack" is commonly applied to dark colored to carbonaceous strata which range in lithologic character from shaly

sandstones to true carbonaceous shales, such beds being characteristic of the Byro formation in the north.

Examination of well samples shows that drillers consistently use the term "chocolate shale" for a red, micaceous, shaly sandstone occurring only, so far as known, in the Kennedy formation. "Shale and sandstone" appear to mean shaly sandstone rather than alternations of shale and sandstone.

WATER HORIZONS

The most important single aquifer appears to be the basal Cretaceous sand, at least 37 wells obtaining their supplies wholly or in part from this bed. Twenty-six obtain a supply wholly or in part from the flint horizon (lower part of Winning series) and 19 wholly or in part from the Kennedy sandstone. At least 40 of the 80 or more wells drilled yielded artesian flows.

Shallow wells show the Wooramel sandstone also to be a good potential aquifer but station owners have generally been discouraged from going to sufficient depths to prove this by encountering salt water in the overlying Byro beds. Waters from the Kennedy sandstone and higher sources, though commonly more or less brackish, are fairly satisfactory for stock.

OIL SOURCE BEDS, COVER, AND RELATED GEOLOGIC FACTORS

SOURCE BEDS

As regards oil source materials, large parts of the section, not only the Permo-Carboniferous but also the Mesozoic and Tertiary, are bountifully provided with organic deposits of various types usually regarded as potential source materials, the conditions in this respect comparing favorably with many a petroliferous province elsewhere.

For example, in the 5,000 feet or so of strata in the Gascoyne series, marine fossils both large and microscopic, together with shales rich in organic matter, are distributed at intervals through at least 60 per cent of the section. Those who favor dark shales and black carbonaceous shales will find them prominently developed in the Byro; others who place weight on the potentialities of calcareous, richly foraminiferal mudstones will find substantial amounts in the Callytharra and Wandagee formations; in fact, fossiliferous horizons of varied types are more numerous and substantially developed here than in the richly petroliferous late Mississippian and Pennsylvanian series of eastern Ohio and Pennsylvania. The contrast is so marked that we venture to state that, had no exploratory drilling in the Carboniferous

fields of eastern Ohio and Pennsylvania yet been done, and had the oil possibilities still remained unknown, comparative studies of source bed potentialities in that region of America and the Northwest Basin region of Australia, would have lead geologists to conclude that the Northwest Basin is the better provided and that the situation as regards the Carboniferous in Pennsylvania and Ohio is none too good.

A review of the literature as well as conversations and correspondence with various people suggests that much of the adverse opinion as to oil possibilities in Australia is based on apprehensions expressed by this or that geologist that glacial conditions which prevailed intermittently in various parts of the Gondwana continent must have been so inimical to plant and animal life in neighboring seas that organic deposits could not have accumulated in sufficient quantities for generation of important amounts of oil. Having inferred that the water of the ancient sea bordering the continent on the west must have been very cool at times, and that on the east even more so, some people are inclined to consider the question so conclusively settled that they deprecate field investigations in search of proof. Reasoning such as this has found wide acceptance in spite of the fact that search in the field for supporting evidence has barely passed the incipient stage.

There is no denying that much excellent paleontological work has been done and is being done in various parts of Australia, a large part of which is still unpublished. The justifiable criticism may, however, be advanced that the sampling has been faulty because the collecting has been at random and confined chiefly to beds rich in macrofossils whereas the sampling should be conducted systematically throughout the section and should include close examination for microfossils. Work of the latter type carried on of late is yielding rich results which will come as a surprise to many people.

As regards the question of sea temperatures F. Chapman states that the successive glaciations had no drastic influence in cooling the shallow sea waters. His views are as follows.[8]

> The Callytharra fauna (Northwest Basin of Western Australia), chiefly comprises crinoidal limestones, rich polyzoal beds and occasional solitary and dendroid corals. On the face of this evidence we may assume that the climatic belt of this area in Upper Carboniferous times was decidedly warm.
>
> The same may be said for the climate of the Lower Marine (Lower Permian) beds of the Fossil Cliff outcrops, Irwin River. There we find a foraminiferal phase showing many species in common with both the Pennsylvanian and Permian of Texas (Upper Carboniferous to Middle Permian). A

[8] Communicated in letter dated March 6, 1935.

marked difference in the Australian foraminiferal fauna of this period, however, is the entire absence, up to the present, of any of the fusulinids (*Verbeekina, Fusulinella* and *Neoschwagerina*), such as are found in Sumatra and Timor (Tobler, 1910). We may, therefore, assume that the warm temperate climatic belt of the Lower Permian of Western Australia was just outside the East Indian tropical zone certainly denoted by those fusulinids.

The successive glaciations found in the Kamilaroi[9] series of Australia could have had no very drastic influence in cooling the shallow marine areas, as we may see by the abundant life of the Lower and Upper Marine series. Its spirifers and productids, especially in Western Australia, closely match the species found in the *Productus* limestone of the Salt Range in India.

Charles Schuchert after reading the opinion of Chapman makes the following remarks which the writers venture to quote.[10]

. . . Chapman's statements are somewhat confusing about the temperature of the seas of Permian time in Australia. He is more or less correct about Western Australia, where the waters were warmer than in Eastern Australia. The Permian of Western Australia is clearly of Tethys (India) and east into Indo-China and southern China, but it is curious to see the absence in Western Australia of all the fusulines, as Chapman says. These are the best warm-water indicators, and their absence in Western Australia must mean that here the waters were too cool for them. Further, in Timor there is a varied ammonite fauna, and yet Western Australia has but a single known form of these warm-water invertebrates. To me, these facts mean that the Western Australia waters were cooler than, say, those of Timor, but by no means so cool as those of Eastern Australia.

I see no reason why cool seas should not put down much carbonaceous material for future oil distillation. So long as plants can live in abundance in sunlit waters, there follows an abundance of animals to feed on them, with the result that on stagnant mud bottoms there will be carbonaceous storage.

The studies of Trask (16) go far toward uprooting certain fixed ideas among geologists regarding the deposition of petroleum source materials. For instance, by finding that sediments accumulating under estuarine and deltaic conditions are commonly poor in organic content, he refutes the popular idea on the importance of estuarine deposits. Equally interesting to those who think of tropical seas as a most favorable environment are his findings on the seeming unimportance of climate. Richly organic sediments are now accumulating in cold waters as well as warm. He finds that the organic content of bottom muds from certain localities in far northern or southern latitudes, including parts of the Bering Sea, the Aleutian Islands, the Baltic Sea and the Kerguelin Islands (Latitude 50° S.), is only moderately less than the content of sediments deposited under similarly favorable

[9] The term Kamilaroi was proposed by David (7) to designate Upper Carboniferous and Permian strata in New South Wales.

[10] Communicated in letter dated November 20, 1935.

environmental conditions in much warmer climatic zones. Under the heading, "General Remarks on Tropical Environments," page 143, he states: "The organic content of tropical nearshore sediments is similar to that of temperate and arctic deposits."

COVER AND PRESERVATION

Clapp (5, 6) concluded not only that source beds are inadequate but also that the entire sequence is too sandy and poorly provided with shale cover to favor the preservation of any oil which may have been generated. The detailed stratigraphic particulars now in hand prove that the possibilities are vastly better than he supposed. In the 5,000 feet thick Gascoyne series, sandstone composes approximately 55 per cent in the south and less than 40 per cent in the north; sandy shales and silty mudstones of fairly compact character are prevalent; and shales of a comparatively impervious type are common at various horizons, particularly in the Wandagee formation (uppermost). Furthermore, the Cretaceous beds include substantial thicknesses of beds which appear to be suitable cover rock.[11]

The present writers conclude that the substantial thickness of shaly strata along with their considerable vertical range provide satisfactory cover. The tendency to lensing and discontinuity of sandy strata such as was noted in parts of the Byro and Wandagee formations, is a favorable feature, since such strata may serve as reservoir rock.

The persistence of the thick Wooramel and Kennedy sandstones, the great aquifers, is an unfavorable feature in that both yield fairly fresh water in most wells although both were largely deposited under marine conditions. These may have served as avenues for escape of hydrocarbons originating in closely associated shaly strata. It is to be remarked, however, that although the comparatively fresh water encountered in these beds bespeaks flushing, there is no proof that such a condition persists farther basinward where the same strata lie deeper and have not been penetrated by the drill. Moreover, even though these sandstones may not have preserved oil accumulations,

[11] It will be of interest in connection with cover rock and related considerations to refer to a paper by Carey Croneis, entitled "Natural Gas in Interior Highlands of Arkansas," published in *Geology of Natural Gas* (1935), pp. 533–73. The principal gas-bearing formations in the Arkansas Valley lie in the Atoka and Hartshorne formations of Pennsylvanian age. The fields are remarkable for their long life, most of them having been producing for more than 10 years. Note the following features: (a) the prevalence of sandstone in the "cover" formations; (b) some of the productive structures show dips up to 20°, for example the Mansfield area, and one, the Morrillton, shows local dips of 45°; (c) carbon ratios range from 79 to 88; and (d) there seems to be no direct connection between the amount of porosity of sandstones and the degree of regional metamorphism as indicated by coal analyses.

prospects in less persistent porous beds in the shales series above and below them may be good.

Various other factors such as the degree of metamorphism, as denoted by carbon ratios and oil and gas indications, are not discussed here. Such data as are available on the degree of carbonization of the coals are favorable (8, page 877). With regard to oil and gas showings no surface occurrences are known, but showings of gas have been encountered in several wells. The water wells, being located almost without exception at positions structurally either synclinal or homoclinal, are unfavorably placed for proving oil and gas possibilities. Moreover, it is not the usual practice in drilling to case off water; therefore, showings of oil and gas even though encountered, may have been overlooked.

All in all, the area possesses so many of the factors commonly accepted as essentials that we venture to express the opinion that if a similarly favorable setting had been transplanted from this remote corner of the world to North America it would, even 20 years ago, have attracted geological investigators and been singled out for decisive attention.

SUMMARY

This paper sets forth particulars regarding the Northwest Basin, one of several extensive areas of late Paleozoic rocks in Australia. Descriptions of stratigraphic details, such as are essential to a consideration of the oil problem, are intentionally made explicit so as to enable the reader to draw his own conclusions. The need for these particulars will be evident on referring to the papers by Clapp dealing with this same area, published 10 years ago (4, 5, 6) in which we are told that this area (like related basins in Western Australia), lacks almost wholly the assemblage of geological factors essential for a petroliferous province. For example, we are told (a) the thickness of Permian and Carboniferous strata is not known greatly to exceed 2,000 feet (though possibly much more); (b) the section is composed almost wholly of sandstones and other porous rocks; (c) shales of a type necessary for cover rock are practically absent not only in the late Paleozoic but also the "Jurassic" and Tertiary; and (d) organic materials of the source bed type are poorly developed. In brief, Clapp conceded that only one of the many requisites actually exists, namely, porous sandstone.

It now turns out that (a) the thickness of the Permo-Carboniferous strata is approximately 7,000 feet; (b) although there are several thick sandstone formations, the proportion of sandstone in the

Gascoyne series (upper 5,000 feet of the section) is only 40–55 per cent; (c) the situation with regard to cover rock is vastly better than was supposed by Clapp, not only in various horizons in the Permo-Carboniferous, but also in parts of the Cretaceous; and (d) deposits of the source bed type appear to be adequate.

Attention is called particularly to the abundant evidence of profuse life during much of Permo-Carboniferous time, despite probable cool sea temperatures—evidence which apparently refutes the often expressed view that the successive glacial stages were completely inimical to life and the accumulation of rich organic deposits.

In view of the results of recent work, the writers conclude that an open-minded attitude on oil possibilities, not only in regard to this area but also other areas of late Paleozoic in Australia, must be adopted and maintained until studies such as now described here have been carried out.

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UPPER PALEOZOIC DEVELOPMENT OF NASHVILLE DOME, TENNESSEE[1]

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ABSTRACT

An isopach map showing the distribution and thickness of the New Providence shale, a structure-contour map on the Chattanooga shale, and a section across central Tennessee have been prepared to illustrate the stratigraphy and structure of the Nashville dome. The dome is shown to have been developed synchronously with mountain-building activity in Appalachia during the Upper Paleozoic. When Appalachia was active, the dome was above sea-level; and when Appalachia was inactive, the dome was covered with sediments. The history of the dome during the Upper Paleozoic is reviewed.

INTRODUCTION

In 1935 the senior writer published a report on the pre-Chattanooga history of the Nashville dome[4] in which he postulated that the dome was developed synchronously with mountain-building activity in Appalachia. During the early Paleozoic history when Appalachia was active, the dome was largely above sea-level; and when Appalachia was inactive, the dome was covered by calcareous sediments. This synchronism between the dome and Appalachia resulted from vertical bulging of the dome by stresses transmitted westward from Appalachia plastically in the deeper rocks of the crust.

The purpose of the present work is to apply further this principle by studying the Upper Paleozoic history of the Nashville dome, and to summarize the stratigraphic and structural history of central Tennessee. The field work for this paper was done during the spring and winter of 1935.

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TOPOGRAPHY

The crest of the Nashville structural dome is expressed topographically as the elliptical Central Basin of Tennessee. This basin occupies the central part of the state and crosses it with a general

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[3] Tennessee Valley Authority. Both authors introduced by L. C. Glenn.

[4] C. W. Wilson, Jr., "Pre-Chattanooga Development of the Nashville Dome," *Jour. Geol.*, Vol. 43 (1935), pp. 449–81.

trend of N. 30° E. Surrounding the basin is the Highland Rim, which is divided by the Central Basin into the Eastern Highland Rim and the Western Highland Rim.

The surface of the Highland Rim is a strikingly flat plain with an average elevation of 1,000–1,100 feet above sea-level. In the western part of the Western Highland Rim the plain gradually slopes westward toward the Mississippi Embayment and is there somewhat lower than the general average. The Highland Rim is bordered on the east by the Cumberland Plateau which has an average elevation of 2,000 feet. As the plateau is approached erosional remnants of the plateau are found as isolated knobs rising prominently above the level of the Rim country. These knobs gradually increase in height and number as one nears the western escarpment of the plateau.

Stratigraphy

In order to discuss the Upper Paleozoic history of the Nashville dome, it is necessary to summarize the areal extent, thickness, and lithologic character of the Mississippian formations present in central Tennessee. For a more detailed description of these formations the reader is referred to Bassler.[5] The publications on the geology of cen-

TABLE I

System	*Series or Group*	*Formation or Member*
Pennsylvanian	Pottsville	
Mississippian	Upper Chester group	Pennington shale
	Middle Chester group	Glen Dean limestone Hardinsburg sandstone Golconda shale Cypress sandstone
	Lower Chester group	Gasper oölite
	Meramec group	Fredonia oölite St. Louis limestone Warsaw formation
	Osage group Keokuk Burlington Fern Glen	 Fort Payne chert ? New Providence shale
	Kinderhook group	— Maury shale member Chattanooga shale Hardin sandstone member
Devonian		

[5] R. S. Bassler, "Stratigraphy of the Central Basin, Tennessee," *Tennessee Div. Geol. Bull. 38* (1932).

tral Tennessee were freely used in compiling parts of the following summary. The subdivisions of the Upper Paleozoic used in this article are shown in Table I.

CHATTANOOGA SHALE

The Chattanooga shale is fissile, black, carbonaceous shale that commonly begins with a dark, phosphatic basal sandstone known as the Hardin sandstone member. The black shale is present throughout central Tennessee, being locally absent only on anticlinal structures. The thickness of the shale varies between 10 and 40 feet on the east, north, and northwest flanks of the dome, but thins to a few feet on the south and southwest flanks, The Hardin sandstone member varies from only a few inches up to a maximum of 15 feet in Hardin and Wayne counties.

The Maury shale member, which occurs at the top of the Chattanooga, is commonly green, glauconitic shale containing phosphate nodules and ranges from a few inches to 2 feet in thickness in much of central Tennessee. In the southwest part of central Tennessee this member becomes as thick as 6 feet and is characteristically green-to-gray phosphatic sandstone and greenish shale.[6] This member is notable for its wide occurrence, being only locally absent, except in Hardin County where it is absent in much of the county.

KINDERHOOK GROUP

With the exception of all, or most, of the Chattanooga shale no beds of Kinderhook age are known in central Tennessee, although they may be discovered low on the flanks of the dome. Bassler[7] in 1912 set up the "Ridgetop shale" as a formation of Kinderhook age, but this has recently been shown to be only a phase of the New Providence shale and to be of Fern Glen age.[8]

OSAGE GROUP

FERN GLEN

New Providence shale.—This formation in central Tennessee is composed of three major facies, green shale, crinoidal limestone, and

[6] W. B. Jewell, "Geology and Mineral Resources of Hardin County, Tennessee," *Tennessee Div. Geol. Bull. 37* (1931), p. 40.

[7] R. S. Bassler, "The Waverlyan Period of Tennessee," *Proc. U. S. Nat. Museum*, Vol. 41 (1912), pp. 209–24.

[8] C. W. Wilson, Jr. and E. L. Spain, Jr., " 'Ridgetop Shale' of Central Tennessee" (abstract). Preliminary list of titles and abstracts, 48th annual meeting, Geological Society of America (December, 1935), pp. 69–70.

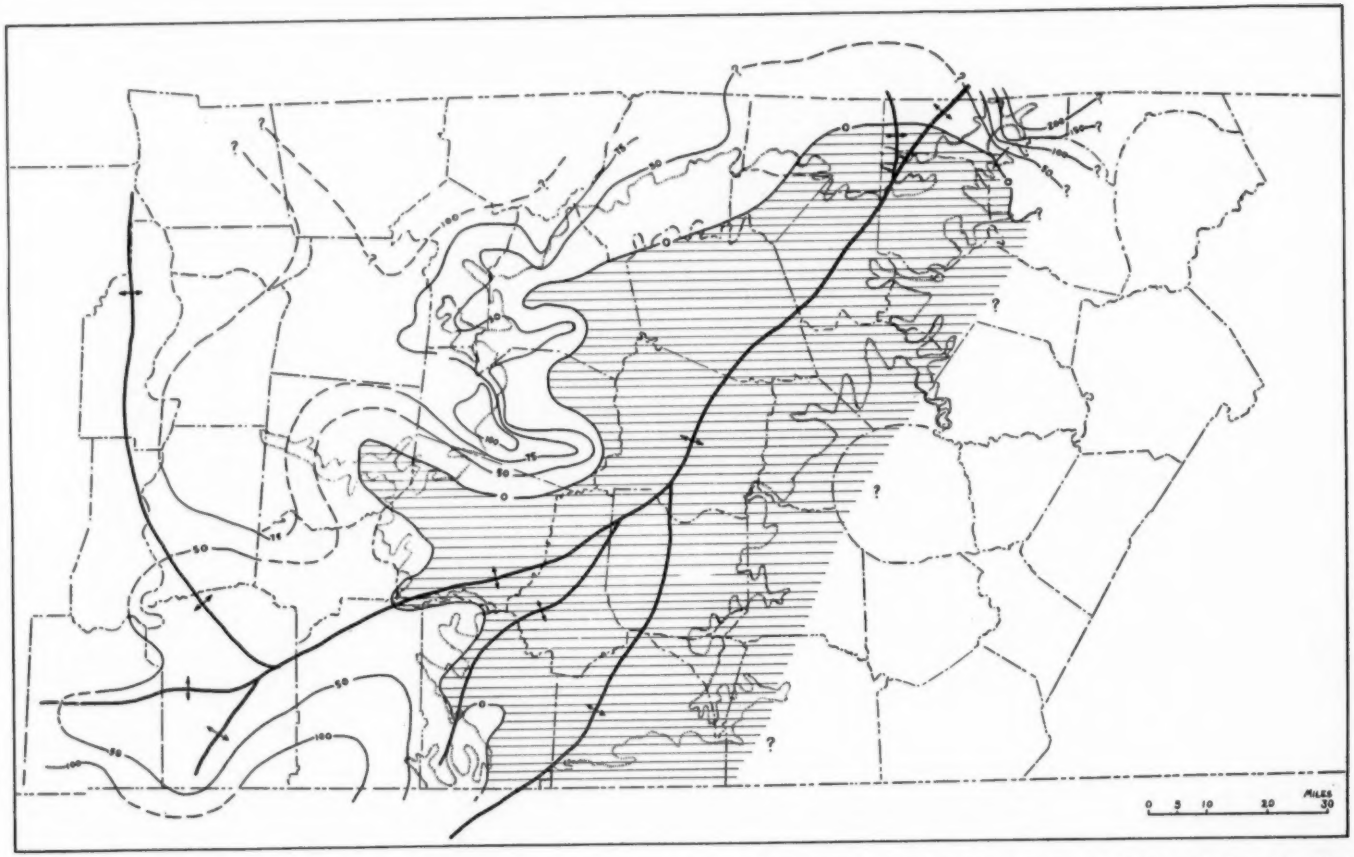

FIG. 1.—Isopach map showing thickness and distribution of New Providence shale in central Tennessee. No New Providence was found within area indicated by ruled lines. Outcrop of Chattanooga shale around Central Basin shown by hachured line.

drab, gray shale. Parts of the latter facies were formerly segregated as the "Ridgetop shale." The occurrence of the New Providence in central Tennessee is limited to the west, north, and south flanks of the Nashville dome, not having been found on the crest or the eastern flank of the dome. The thickness varies from a feather edge to 250 feet in Clay County, Tennessee. Figure 1 shows the New Providence thickening toward the north, west, and south from the crest of the dome. The structural control of the thickness of the New Providence, as shown in Figure 1, is very striking.

BURLINGTON

Strata of Burlington age have not yet been definitely identified in central Tennessee, but it is suggested from stratigraphic and reconnaissance faunal studies that the Burlington may be represented in strata assigned to the upper part of the New Providence shale and the lower part of the Fort Payne chert. The contact between the New Providence and the Fort Payne in central Tennessee seems to be a gradational contact, eliminating the possibility of an intervening record having been lost by erosion, except in Hardin County where a marked unconformity is present, causing the Fort Payne to rest locally on Devonian and Silurian formations.[9]

KEOKUK

Fort Payne chert.—This formation is commonly a massive-to-thin-bedded, dark bluish gray, siliceous and argillaceous limestone containing bands of dark chert, and weathering to a buff cherty and siliceous mass. The Rosewood shale, which has commonly been considered a phase of the Fort Payne, is locally present in north-central Tennessee. The Fort Payne is everywhere present on all flanks of the dome, and varies in thickness from 75 to 275 feet.

MERAMEC GROUP

Warsaw formation.—The Warsaw formation consists of gray-blue, sandy, granular limestone, calcareous sandstone, and shale that together average between 60 and 100 feet in thickness. The formation occurs persistently throughout central Tennessee. It weathers into bright red soil that contains blocks of porous chert.

St. Louis limestone.—This formation is commonly massive-to-medium-bedded, fine-grained, blue-to-gray limestone. It weathers to red soil containing many white chert fragments, spherical chert concretions, and fragments of *Lithostrotion*. The average thickness ranges

[9] W. B. Jewell, *op. cit.*, p. 43.

from 120 to 200 feet. The formation occurs widely, capping large parts of the Eastern Highland Rim and the northern part of the Western Highland Rim where it is the youngest Paleozoic formation present. It formerly extended over most, or more probably all, of central Tennessee.

Fredonia oölite (*Ste. Genevieve*).—The Fredonia oölite is light gray-to-white oölitic limestone that averages about 120 feet in thickness. Its present distribution in central Tennessee is limited to the outlying knobs on the eastern part of the Eastern Highland Rim and to the western escarpment of the Cumberland Plateau.

LOWER CHESTER GROUP

Gasper oölite.—This formation consists of 100–160 feet of gray limestone some of which is oölitic, and other parts fine-grained, gray limestone. It is separated from the underlying Fredonia oölite by a 6-foot zone of calcareous shale and limestone conglomerate. The distribution is similar to that of the Fredonia oölite.

MIDDLE CHESTER GROUP

Cypress sandstone.—This formation is gray-to-buff, medium-grained sandstone that averages about 30 feet in thickness. It caps many of the flat-topped knobs and long ridges or spurs on the eastern part of the Eastern Highland Rim and commonly forms a terrace high on the western face of the Cumberland Plateau.

Golconda shale.—Soft green and red shales, locally calcareous, and commonly about 25 feet in thickness, overlie the Cypress sandstone at several localities.

Hardinsburg sandstone.—This thin sandstone occurs only locally along the western escarpment of the Cumberland Plateau in Tennessee. It is probably the thinned equivalent of the much thicker and more persistent Hartselle sandstone of Alabama.

Glen Dean limestone.—The Glen Dean limestone is massively bedded, crystalline, blue limestone that varies from 120 to 200 feet in thickness and that occurs high on the escarpment of the Cumberland Plateau.

UPPER CHESTER GROUP

Pennington shale.—The uppermost formation of the Mississippian system exposed along the Cumberland Plateau in Tennessee is the varicolored Pennington shale. This shale, which varies up to 300 feet in thickness, contains many lenses of limestone and sandstone. It is not present on Short Mountain, Cannon County, Tennessee, having been removed by pre-Pottsville erosion.

POTTSVILLE SERIES

The sandstone, conglomerate, and shale of the Pottsville series rest non-conformably on the eroded surface of the underlying Mississippian formations. Beds of this series cap the Cumberland Plateau and its outliers, the westernmost of which is Short Mountain. The easternmost occurrence of Pottsville on the western flank of the Nashville dome is in Warren, Butler, Logan, and Todd counties, Kentucky.

STRUCTURE

REGIONAL FEATURES

The Nashville dome, which occupies all of central Tennessee, is a large anticlinal structure on the southern end of the Cincinnati arch. Figure 2, which is a structure-contour map on the top of the Chattanooga shale, shows the general size and shape of the dome as developed by post-Chattanooga diastrophism. The axis of post-Chattanooga uplift extends southwestward from Clay County, Tennessee, to a point about 10 miles south-southwest of Murfreesboro, Rutherford County, where it divides into two axes. The eastern of these two continues southward toward Giles County and crosses the Tennessee-Alabama boundary near Elk River. The western axis extends west-southwestward from Rutherford County to north-central Lawrence County where it turns westward to continue into Wayne County and Hardin County.

The Chattanooga shale reaches an elevation of 1,275 feet above sea-level in south-central Rutherford County. From this locality the axis pitches about 8 feet per mile both northeast and southwest. The average dip on the sides of the dome is about 16 feet per mile. Locally the dip is much steeper than the regional dip and may reach several degrees for short distances.

The Nashville dome is separated from the Jessamine dome (central Kentucky) by a structural saddle that crosses the Cincinnati arch between the two domes. In this saddle the Chattanooga shale is 700 feet lower than it is on the crest of the Nashville dome where it is 1,275 feet above sea-level.

MINOR FOLDS

Many small folds occur on the gently dipping flanks of the dome. These small structures cause considerable variation in local dips. The folds are commonly much less than 100 feet in structural relief, and the dips on these folds are as steep as 10° but average about 2°. These minor folds are irregular in shape, and show a complete lack

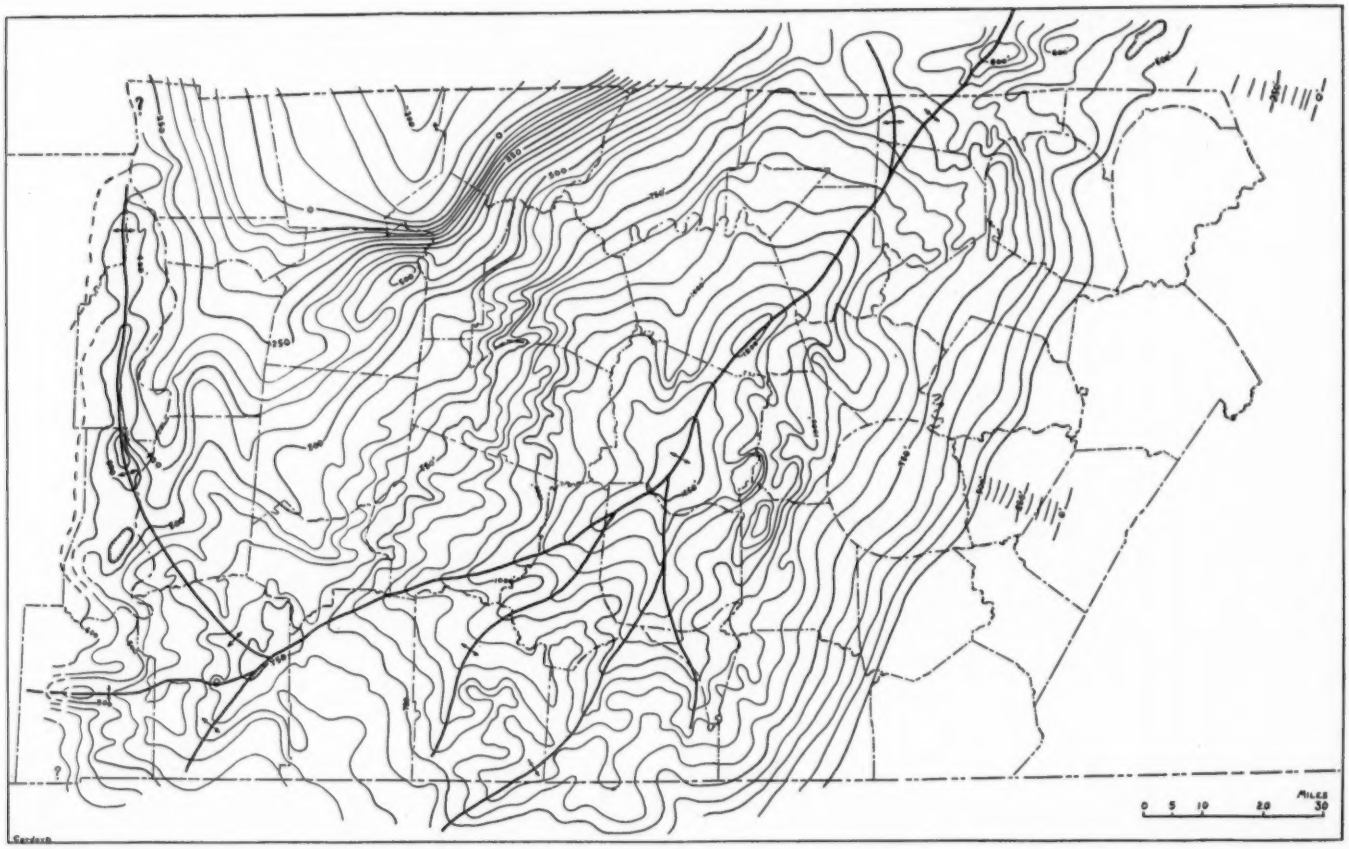

FIG. 2.—Structure contour map of central Tennessee drawn on Chattanooga shale. Contour interval, 50 feet. Modified after Wilson.

of parallelism of axes, having no orientation suggestive of a general pattern. This lack of orientation is believed to indicate the origin of the minor folds by differential vertical uplift (as would accompany the irregular vertical bulging of the Nashville dome by stresses transmitted plastically in the deeper rocks of the crust), and to signify an almost complete lack of directional stresses transmitted horizontally in the outer rocks of the crust.

During the Paleozoic the dome[10] was uplifted many times, the axis of greatest uplift shifting east-west and north-south in accord with the intensity and direction of the stresses. The small, local folds on the flanks of the dome, once established as anticlines or synclines, remained so throughout all subsequent diastrophism. Such an origin of folds implies greater closure with depth than is suggested by surface closure, successively steeper dips with depth, and continuation of folds across unconformities.

RELATIONSHIP TO APPALACHIA

The stresses that caused the structural development of the Nashville dome are believed to have originated from the geanticline, Appalachia, that lay east of the Appalachian geosyncline. The very striking sympathetic synchronism between the Paleozoic history of Appalachia and that of the Nashville dome is summarized in Figure 3. Column 1 of this figure is a generalized summary of the characteristic sediments deposited in the Appalachian geosyncline in Virginia, Tennessee, and Alabama during each of the geologic time units. This summary is compiled chiefly from the work of Butts in Virginia[11] and Alabama.[12] The relief and elevation of Appalachia necessary to have supplied the sediments in column 1 are graduated into 4 groups in column 2; (1) high, (2) moderately high, (3) moderately low, and (4) low, corresponding, respectively ,with (1) great thickness of predominantly clastic sediments, (2) appreciable thickness of clastics with some fine clastics and limestone, (3) fine clastics and limestone, and (4) predominantly limestone.

The record of deposition on the Nashville dome is summarized in column 3, showing that the dome may have been (1) completely covered by thick limestones (100 feet or more) as in the Keokuk,

[10] The reader is referred to the paper by the senior writer on "The Pre-Chattanooga Development of the Nashville Dome," *Jour. Geol.*, Vol. 43, No. 5 (July–August, 1935), pp. 449–81, for discussion on the shifting of the axis of the dome, nature of uplift of the dome, et cetera.

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[12] C. W. Butts, "Geology of Alabama," *Alabama Geol. Survey Spec. Rept. 14* (1926).

GEOLOGIC TIME		1 CHARACTERISTIC SEDIMENTS DEPOSITED IN THE APPALACHIAN GEOSYNCLINE IN VIRGINIA, TENNESSEE, AND ALABAMA	2 INFERRED ELEVATION AND RELIEF OF APPALACHIA	3 RECORD OF DEPOSITION ON THE NASHVILLE DOME	4 INFERRED ELEVATION OF THE NASHVILLE DOME IN REFERENCE TO SEA LEVEL
P.	POTTSVILLE	SANDSTONE SHALE CONGLOMERATE	VERY HIGH	COMPLETELY COVERED BY CLASTIC SEDIMENTS FROM APPALACHIA	ABOVE, BUT NOT HIGH ENOUGH TO PREVENT COVERING BY SEDIMENTS
MISSISSIPPIAN	UPPER CHESTER	SHALE AND SANDSTONE	HIGH	(REMOVED BY EROSION)	POSSIBLY BELOW PART OF TIME BUT ABOVE BEFORE POTTSVILLE
	MIDDLE CHESTER	LIMESTONE THIN SHALE AND SANDSTONE	LOW EXCEPT FOR SHORT INTERVALS	LIMESTONE WITH THE THIN CYPRESS SANDSTONE AT BASE (200')	BELOW
	LOWER CHESTER	LIMESTONE AND SOME SHALE	LOW	LIMESTONE (150')	BELOW
OSAGE / MERAMEC	STE. GENEVIEVE	LIMESTONE AND SOME SHALE	LOW	LIMESTONE (120')	BELOW
	ST. LOUIS	LIMESTONE AND SOME SHALE	LOW	LIMESTONE (175')	BELOW
	WARSAW	LIMESTONE ARGILLACEOUS AND SANDY	LOW	LIMESTONE ARGILLACEOUS AND SANDY (75')	BELOW
	KEOKUK	CHERTY LIMESTONE PARTLY ARGILLACEOUS	LOW	CHERTY LIMESTONE (150')	BELOW
	BURLINGTON	SHALE AND LIMESTONE	MODERATELY LOW	UNLESS LOCALLY REPRESENTED IN BASE OF OVERLYING CHERTY LIMESTONE	ABOVE, EXCEPT POSSIBLY THE LOWEST PARTS OF FLANKS
	FERN GLEN	SHALE AND SOME SANDSTONE	MODERATELY HIGH	SHALE (0'-200')	CREST OF DOME - ABOVE LOW FLANKS - BELOW
	KINDERHOOK	SHALE AND SOME SANDSTONE	MODERATELY HIGH	UNLESS LOCALLY REPRESENTED BUT NOT THE RIDGETOP	ABOVE EXCEPT POSSIBLY THE LOWEST PARTS OF FLANKS
	CHATTANOOGA	SHALE	MODERATELY LOW	SHALE (10'-40')	BELOW
DEVONIAN	ERIAN TO CHEMUNG	SHALE AND SANDSTONE	MODERATELY HIGH	—— —— ——	ABOVE
	ULSTERIAN	SHALE AND LIMESTONE	MODERATELY LOW	LIMESTONE (12') ONLY ON NORTHWEST FLANK OF DOME	ABOVE (EXCEPT FOR DEPOSITION OF 'PEGRAM')
	ORISKANY	PREDOMINANTLY SANDSTONE	HIGH	—— —— ——	ABOVE
	HELDERBERG	LIMESTONE SANDSTONE SHALE	MODERATELY HIGH	—— —— ——	ABOVE
SILURIAN	CAYUGAN	LIMESTONE SANDSTONE SHALE	MODERATELY HIGH	—— —— ——	ABOVE
	LOCKPORT	LIMESTONE	LOW	LIMESTONE AND ARGILLACEOUS LIMESTONE (150')	BELOW (EXCEPT FOR HIGHEST PART OF DOME)
	CLINTON	SANDSTONE AND SHALE	HIGH	ARGILLACEOUS LIMESTONE (10')	ABOVE (EXCEPT FOR DEPOSITION OF OSGOOD)
	ALBION	SANDSTONE	HIGH	LIMESTONE (20')	ABOVE (EXCEPT FOR DEPOSITION OF BRASSFIELD)
ORDOVICIAN	RICHMOND	SHALE AND SANDSTONE	HIGH	LIMESTONE AND SHALE (50')	ABOVE (EXCEPT FOR DEPOSITION OF FERNVALE AND ARNHEIM)
	MAYSVILLE	SHALE AND SOME SANDSTONE	MODERATELY HIGH	LIMESTONE AND ARGILLACEOUS LIMESTONE (50')	ABOVE (EXCEPT FOR DEPOSITION OF LEIPERS)
	EDEN	SHALE	MODERATELY LOW	—— —— ——	ABOVE
	TRENTON	LIMESTONE	LOW	LIMESTONE (300')	BELOW
	BLACK RIVER	LIMESTONE	LOW	LIMESTONE (100')	BELOW
	BLOUNT	SHALE LIMESTONE AND SOME SANDSTONE	MODERATELY HIGH	—— —— ——	ABOVE
	STONES RIVER	LIMESTONE	LOW	LIMESTONE (275'+)	BELOW

FIG. 3.—Chart illustrating sensitive synchronism between activity of Appalachia and Paleozoic development of Nashville dome. Lower Paleozoic after Wilson.

Warsaw, St. Louis, et cetera, that represent most, or all, of the duration of each of these times; (2) covered by only relatively thin sediments that represent only a short part of the time, as possibly during the Kinderhook (Chattanooga shale); or (3) partially covered by sediments deposited only on the flanks of the dome, as in the Fern Glen, and possibly the Burlington.

From the record of deposition on the dome the writers infer (column 4) its elevation with reference to sea-level for each time unit; whether the dome was: (1) below sea-level during most, or all, of the time; (2) below sea-level only a short part of the time and above the remaining time; or (3) the higher part of the dome remained above sea-level while the flanks were invaded by the sea.

The Upper Paleozoic development of the Nashville dome as shown on this chart seems to be in perfect accord with the principle of *sensitive synchronism*, for the same sympathetic relationship between the histories of Appalachia and the Nashville dome existed as they had during the early Paleozoic. The conclusions drawn from this study is that when Appalachia was being subjected to tectonic stresses and hence had high or moderately high relief it supplied clastic sediments to the Appalachian geosyncline. During such times the Nashville dome was relatively high and was either above sea-level for most of the time, or was submerged only on the outer flanks. When Appalachia was not being, or had not recently been, subjected to tectonic stresses, it had low relief and elevation, and limestone was deposited in the geosyncline. At such times the Nashville dome was relatively low and was probably below sea-level for most, or all, of the time.

History of Nashville Dome

Age of dome.—If the sympathetic activity of Appalachia and the dome is accepted, it seems logical to assume that the dome was in existence and active during the Cambrian period, as a great thickness of clastic sediments was deposited in the Appalachian geosyncline during that period, implying high relief and elevation of Appalachia. Such activity of Appalachia must have had sympathetic response in central Tennessee in the initial upward bulging of the Nashville dome.

Lower Paleozoic history.—During the Cambrian, Ordovician, Silurian, and Devonian, Appalachia and the dome were closely synchronous, for when Appalachia was low the dome was low, and when Appalachia was high the dome was high (Fig. 3).

Chattanooga shale.—Following the post-Middle Devonian erosion, the Chattanooga shale was deposited across the truncated edges of strata ranging in age from the Trenton to the Ulsterian. This forma-

tion, which averages between 10 and 40 feet in thickness throughout central Tennessee, thins on the south and southwest flanks of the dome, suggesting slight uplift on the southern end of the dome during deposition. The local thinning and absence of the shale on anticlinal structures likewise suggest movement during, or shortly following, deposition.

MISSISSIPPIAN SYSTEM

KINDERHOOK GROUP

Probably most, or all, of the Chattanooga shale is of Kinderhook age, but the writers prefer not to commit themselves on this question at this time. For this reason the Chattanooga is treated as a separate unit in this report. During the remainder of Kinderhook time the dome was apparently above sea-level as no sediments of Kinderhook age (other than probably the Chattanooga shale) are known in central Tennessee.

OSAGE GROUP

Fern Glen.—The New Providence shale was deposited on the north, west, and south flanks of the dome, but the crest and the higher part of the east flank remained above sea-level. This shale is thought to have extended only a very short distance higher on the flanks of the dome than is shown in Figure 1, because very little of the shale could have been removed by erosion without disturbing the underlying, ubiquitous Maury shale member of the Chattanooga shale. It is believed that the dome with its covering of the Maury shale remained close to sea-level during the invasion of the Fern Glen sea, and the argillaceous sediments present in the New Providence shale were brought into central Tennessee and distributed around the north, west, and south flanks of the slightly bulged dome, the crest of which was just high enough not to be covered by this sea and its sediments. The clastic material in the New Providence shale must have been carried to central Tennessee as there was no local source for such material, that region being covered with a blanket of Chattanooga shale (and the Maury shale member). The thickness of the New Providence (Fig. 1) is closely related to the structure of central Tennessee, being absent or thin on anticlinal axes and thick in synclinal areas.

Burlington.—No sediments of this age are definitely known in central Tennessee, so it is thought that the crest of the dome remained above sea-level as Fort Payne chert with Keokuk fossils rests on the Maury shale member on the crest and higher flanks of the dome. The contact between the Fort Payne and the New Providence

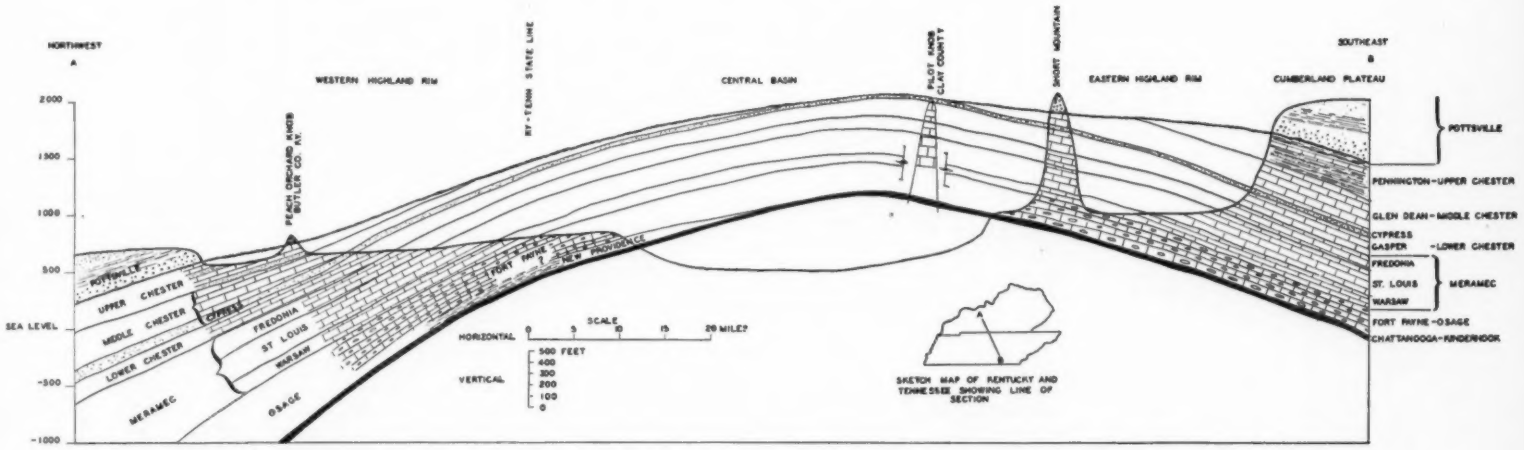

FIG. 4.—Northwest-southeast section across central Tennessee and Kentucky showing general structure and Upper Paleozoic stratigraphy of Nashville dome.

on the north, west, and south flanks of the dome appears to be a gradational contact (except in Hardin County). It seems probable that the New Providence sea transgressed on the north, west, and south flanks of the dome. Following this initial transgression was an apparent pause of non-deposition during part, or all, of Burlington time, in which time if Burlington sediments were deposited they were laid down on the flanks of the dome similar to the New Providence and did not cover the higher flanks or crest. The upper part of the New Providence and the lower part of the "off-dome" Fort Payne must include the Burlington.

Keokuk.—The dome remained sufficiently low for the sea to continue the transgression and to cover central Tennessee, depositing an average of 150 feet of cherty limestone, the Fort Payne chert, throughout the region and over the crest of the dome.

MERAMEC GROUP

Warsaw, St. Louis, and Fredonia (Ste. Genevieve).—The dome remained low and seas of these units of time deposited uniform sheets of sediments that covered central Tennessee with an average total thickness of 375 feet.

CHESTER GROUP

Lower and Middle Chester.—During this time the dome was apparently low as the formations deposited in eastern Tennessee are present in characteristic development on Short Mountain, Cannon County, which is only 20 miles east of the axis of post-Chattanooga uplift of the Nashville dome and which is sufficiently high on the structure to necessitate a normal extension over the crest of the dome (Fig. 4). The Golconda shale and Hardinsburg sandstone, which are commonly missing in Tennessee, are absent from the section on Short Mountain.

Upper Chester.—The relative elevation of the dome can not be determined for the Upper Chester, but it is definite that the dome was bulged sufficiently high above sea-level during the latter part of this unit of time and preceding Pottsville deposition to permit erosion tc strip all the Upper Chester and possibly most of the Middle Chester formations off the dome before the deposition of Pottsville sediments. Evidence for this is seen in the absence of the Pennington shale (Upper Chester) and the marked thinning of the underlying Glen Dean limestone (Middle Chester) as high up the eastern flank of the dome as Short Mountain. An eastward projection of the Chester formations and the Pottsville across the crest of the dome and the con-

sideration of the more resistant character of the Cypress sandstone (Middle Chester) suggest that erosion had removed the Mississippian formations down to the Cypress sandstone, which was left possibly a stripped "domed-surface" on the crest of the dome, before the overlapping by the Pottsville sediments. This postulation is illustrated in Figure 4.

PENNSYLVANIA SYSTEM

POTTSVILLE SERIES

The sandstone, shale, and conglomerate characteristic of the Pottsville in the Appalachian region are thought to have overlapped the truncated edges of the Mississippian formations and to have been deposited on the dip slope of the Cypress sandstone forming the crest of the dome. This postulation is made as a projection of the dip of the Pottsville sediments from the western escarpment of the Cumberland Plateau at Bon Air to Short Mountain would necessitate its continuation over the highest part of the Nashville dome (Fig. 4). Such a projection would demonstrate previous continuation of Pottsville sediments completely over the Nashville dome to have united with Pottsville sediments in Logan, Todd, Warren, and Butler counties, Kentucky (Western Interior Coal Basin).

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USE OF INSOLUBLE RESIDUES FOR CORRELATION IN OKLAHOMA[1]

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ABSTRACT

This paper shows the value of insoluble residues as an important supplement to the methods for determination and correlation of surface and subsurface strata. Beds similar in appearance and composition may be differentiated, a practical value in determining oil structures. A change in lithologic conditions is reflected by a change in residues. Many diagnostic characteristics such as arenaceous *Foraminifera*, silicified fossils, authigenic crystals, sand grains, types of chert, and other residues are liberated, concentrated, and exposed by the solution of the obscuring matrix. The pre-Mississippian formations of central and eastern Oklahoma, from the Arbuckle Mountains to the Ozarks, are correlated by means of samples from wells and outcrops. The beds of the Simpson formation which change rapidly, both laterally and vertically, may be traced readily when studied according to zones instead of separate units. When lateral changes in the type of residue are noted, correlations may be extended for long distances, but not over long intervals between samples.

INTRODUCTION

The purpose of this investigation is to study and describe the insoluble residues of the pre-Mississippian sediments of Oklahoma; to trace and correlate the beds of pre-Mississippian age by means of the residues of well samples and outcrop samples from the Arbuckle Mountains to the Oklahoma part of the Ozark Plateau; to study and describe the arenaceous *Foraminifera* of the pre-Mississippian formations; and to evaluate the use of insoluble residues for subsurface study and correlation.

ACKNOWLEDGMENTS

The writer is especially indebted to Carey Croneis and F. J. Pettijohn of the University of Chicago under whose direction the paleontological and mineralogical work was done.

Special thanks are given to H. S. McQueen of the Missouri Bureau of Geology and to C. A. Merritt of the University of Oklahoma for introduction to the method. V. E. Monnett of the University of Oklahoma provided facilities for the solution and filing of the samples. G. D. Gibson aided greatly in the labor of dissolving several thousand samples.

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Thanks are expressed to the various petroleum companies and to the geologists representing them from whom samples were secured, especially to J. T. Richards and Max Littlefield of the Gypsy Oil Company, R. L. Clifton of the Champlin Oil Company, John Ware of the Skelly Oil Company, H. S. Thomas of the Slick Estates, S. W. Lowman of the Mid-Continent Petroleum Corporation, J. C. Finley of the Phillips Petroleum Company, and Zenas Stucky of the Empire Oil and Gas Company.

Acknowledgment is given to J. K. Knox, D. A. McGee, and Norval Ballard of the Phillips Petroleum Company for helpful discussion and aid given during the summer spent in their laboratories.

C. E. Decker kindly made available the residues of the type sections of the Arbuckle and Simpson formations made by C. A. Merritt, which are now on file at the Oklahoma Geological Survey.

L. E. Workman of the Illinois Geological Survey was very helpful with his criticism and suggestions.

DEFINITION OF INSOLUBLE RESIDUES

The term "insoluble residue," as used here, includes all material remaining after a sample has been digested by cold dilute hydrochloric acid. The dilute acid was made by taking equal volumes of water and concentrated commercial hydrochloric acid. The time allowed for digestion varied from 3 to 24 hours. Natural residues are left by weathering, but such residues and those due to solution by reagents other than hydrochloric acid are not considered in this paper. The term "siliceous residue" can not be used for those described here since many of the residues are not siliceous.

LOCATION OF AREA

The region covered by this study is a rhomboid-shaped area in central, eastern, and northeastern Oklahoma covering about 13,000 square miles. The Arbuckle Mountains are in the southwestern part of the area and the Oklahoma portion of the Ozark Plateau is in the northeastern part of the area.

HISTORY AND PREVIOUS WORK ON INSOLUBLE RESIDUES

The first paper dealing with insoluble residues appeared in 1888 by E. Wethered.[3] Since that time many workers have used residues for the investigation of various problems. H. S. McQueen[4] of the Missouri Bureau of Geology was the first to use residues on a large scale

[3] E. Wethered, *Geol. Mag.*, Decade III, Vol. 5 (1888), p. 139.

[4] H. S. McQueen, "Insoluble Residues as a Guide to Stratigraphic Study," *Missouri Bur. Geol. Fifty-Sixth Bien. Rept.* (1931), Appendix.

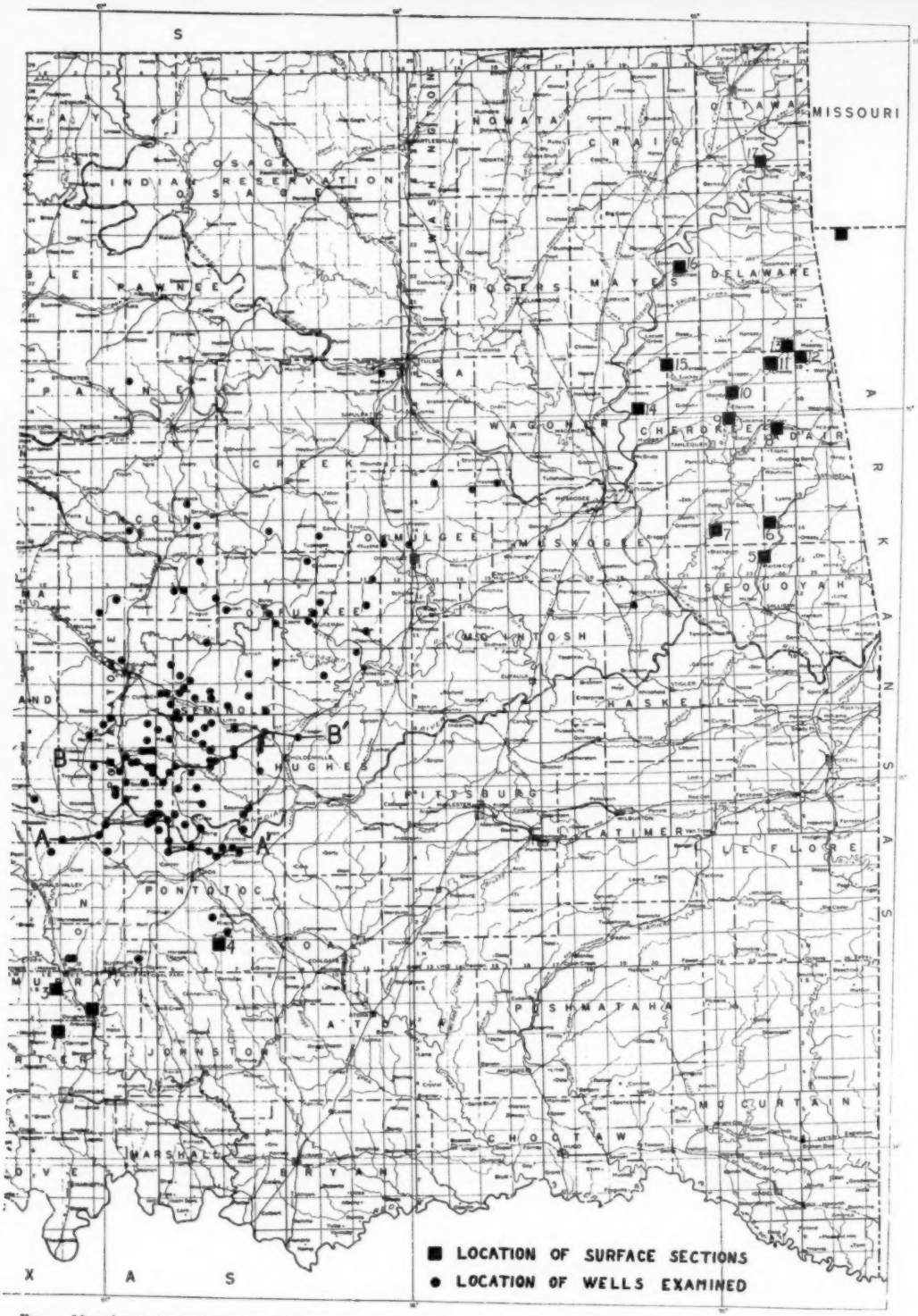


FIG. 1.—Map of central and northeastern Oklahoma, showing location of wells and outcrops sampled for study of insoluble residues; also showing location of cross sections *AA'* and *BB'* of Figure 13. Location of surface sections: 1, Tulip Creek; 2, Dougherty; 3, Lick Creek; 4, Franks, Murray Lane; 5, Marble City; 6, Bunch; 7, Cookson; 8, Proctor; 9, Fite Ranch; 10, Eagle's Nest; 11, Chewey, Illinois River; 12, Rock Creek; 13, Flint Creek; 14, Clear Creek; 15, Spring Creek; 16, Spavinaw Dam; 17, N.E.O. Camp on Grand River.

for practical correlation purposes. He started his investigation in 1924 and published the results in 1931. At that time he had over 30,000 samples, chiefly from the Cambrian and Ordovician rocks of Missouri. He also studied samples of material from adjacent states in order to extend the Missouri correlations. C. A. Merritt[5] of the University of Oklahoma has studied the residues from several sections of the Simpson formation and the Arbuckle limestone in the Arbuckle Mountains. J. W. Ockerman[6] of the Kansas Geological Survey has studied the residues of the Hunton and Viola limestones from samples secured from wells drilled in the vicinity of Topeka, Kansas. L. E. Workman of the Illinois Geological Survey has employed the residue method very efficiently in subdividing the limestone of the Silurian of northern Illinois, but has not published as yet the results of his work. His study includes beds equivalent to Oklahoma beds. G. E. Burpee and W. L. Wilgus[7] have used insoluble residues for a study of the Permian beds in the Eunice oil field of New Mexico.

PREPARATION OF SAMPLES

Samples were collected at intervals of one foot where possible, but where sandstone or shales occurred they were taken at greater intervals. Altogether, 56 localities were measured in the Ozark area of northeastern Oklahoma and part of the adjacent area in Arkansas. The beds included ranged from Ordovician to Pennsylvanian, but the Mississippian were later omitted as the investigation became too bulky for practical value. Furthermore, the well samples above the base of the Mississippian are chiefly from rotary wells and unsatisfactory to use due to cavings from the overlying beds. The widespread unconformity at the base of the Chattanooga shale was another reason for omitting the Mississippian. In all, 6,300 samples were dissolved and studied, of which about 5,000 were from wells in central and southern Oklahoma.

Well cuttings were taken from rotary and cable-tool wells. The cable-tool cuttings were preferable since they were less contaminated by cavings, but the rotary cuttings were used in order to test the value of all kinds of material. Since most wells in Oklahoma are drilled

[5] C. A. Merritt and C. E. Decker, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Circ. 15* (1931).
C. A. Merritt and C. E. Decker, "Physical Characteristics and Stratigraphy of the Simpson Group," *ibid., Bull. 55* (1931).

[6] J. W. Ockerman, "Insoluble Residues of the Hunton and Viola Limestones of Kansas," *Jour. Sed. Petrol.*, Vol. 1 (1931), p. 43.

[7] G. E. Burpee and W. L. Wilgus, "Insoluble Residue Methods and Their Application to Oil Exploration Problems," *Min. and Met.* (October 7, 1935).

with rotary tools, the application of the use of insoluble residues is of significance. In many cases, limestone fragments had to be picked out and then dissolved. Since most of the wells have casings set on the Hunton limestone or the Fernvale limestone, the samples below those horizons were generally excellent. Twelve grams of material was used since many well samples have been cut to such a size that a larger amount would destroy the major portion of the available sample. The writer is deeply grateful to the geologists who furnished even a small amount of their irreplaceable material.

The cost of making insoluble residues, including bottles, labels, corks, acid, et cetera was about $.015 per sample. The time necessary for solution of 12 grams of samples is 2–6 hours, depending on the size of the fragments. Approximately 50–100 samples may be made and studied in one day by one person, depending on the number of beakers available. The following equipment is needed for the preparation and examination of 1,000 samples weighing 12 grams each.

10 gallons of concentrated commercial hydrochloric acid which should be diluted with an equal part of water
3 or 4 dozen 250-cubic centimeter beakers or 10-ounce tumblers
Sand bath or oven for drying samples
7 gross each of 2-dram glass vials, labels, and corks
Binocular microscope and miscellaneous material

In making a residue, the writer used 5–10 cubic centimeters of acid on first treatment; otherwise, the initial effervescence of fine particles would cause loss of material over the edge of the beakers. Then each sample was covered with about 75 cubic centimeters of acid and allowed to stand until effervescence ceased. The fine clay and precipitates were decanted and additional acid applied until complete digestion of soluble matter was insured. Smooth rounded pellets indicated incomplete digestion. After digestion the samples were washed several times to eliminate colloidal clay and fine matter, soluble salts, and all traces of unused acid. Gypsum frequently forms, which obscures the particles when dry. After drying, the residues were bottled, labelled, and filed, and subsequently examined, described, and interpreted. Accurate weighing of the samples was not necessary since well cuttings are not absolutely pure, and accuracy is offset by the contamination. The writer used a graduated cylinder for determining the percentage of residue in reference to the original volume and considered the method satisfactory.

DESCRIPTION OF RESIDUES

The residues may be classed according to their derivation from allogenic or authigenic constituents of the original rock. Allogenic

constituents are those derived from earlier sediments and authigenic constituents are those formed contemporaneously with, or subsequently to, the deposition of the sediment.[8] The writer uses the term "syngenetic" to include residues from constituents formed contemporaneously with the sediment and the term "epigenetic" to include the residues from constituents formed subsequently.

CLASSIFICATION OF RESIDUES

Allogenic	*Authigenic*	
	Syngenetic	*Epigenetic*
Silt	Fossils	Replaced fossils
Sand	Chert	Chert
Shale fragments	Glauconite	Quartz crystals
Mineral fragments		Anhydrite crystals
		Siliceous oölite
		Interstitial silica
	Pyrite	Pyrite
	Dolocasts formed from dolomite crystals	Dolocasts formed from dolomite crystals

ALLOGENIC

The sand grains are chiefly quartz, though feldspar and various heavy minerals occur in small amounts. Heavy minerals were not especially investigated in this study. The sand grains are frosted, subangular to rounded, and range from 0.05 to 1.2 millimeters in diameter. Many grains with an etched surface were seen; others were somewhat polished. Considerable sand occurred which had been frosted after secondary enlargement of the grains. The prism angles were still observable though somewhat rounded. Several samples exhibited polished rounded sand grains which varied from 0.05 to 0.4 millimeter in diameter. Anderson[9] has shown that frosting occurs more readily from scour in agitated water than by wind action. The polished grains were probably rounded by scour but were polished in gently agitated water.

Sand grains enlarged by secondary addition of silica are very common in the residues. The degree of enlargement grades from incipient crystals to well formed prisms and pyramids, and in some cases to tightly locked grains where crystal faces are distorted by the pressure of growth. Many of the crystal faces show multiple facets. Although the growth is due to secondary causes, the sand grains are allogenic

[8] P. G. H. Boswell, *Mineralogy of Sedimentary Rocks*, Thomas Murby and Company, London (1933), p. 1.

[9] G. E. Anderson, "Experiments on the Rate of Wear of Sand Grains," *Jour. Geol.*, Vol. 34 (1926), pp. 144–58.

and when they occur in a residue they must be classed as grains derived from allogenic constituents.

One type of secondary enlargement is found, which seems so unusual that a description of it is given (Fig. 2). The sand grains show many minute elongated prisms of quartz extending from the surface of the grains. The grains are very rough, appear frosted, and the secondary growths appear to radiate. However, all the prisms attached to a single grain have the same extinction and optical orientation of the parent grain. The sand grains are found in quantities of less than one

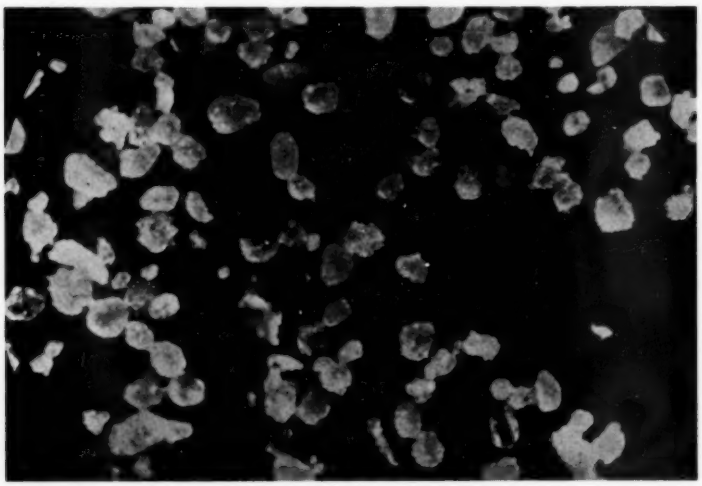


FIG. 2.—Phenomenal secondary growth of sand grains with numerous tiny elongate crystals oriented optically with parent grain and giving very rough frosted appearance. From base of exposure of Cotter dolomite at White River bridge east of Rogers, Arkansas. (×20)

per cent in beds where other evidence of the addition of silica as chert and replaced fossils is lacking. The grains are best shown in samples taken from the base of the Yellville (Powell and Cotter) at the bridge on White River near Rogers, Arkansas. Similar grains are found in abundance in the Arbuckle limestone. All occurrences so far have been from dolomite and limestone of Ozarkian and Canadian age.

Most of the fine particles of silt and clay are decanted when the residues are washed. However, aggregates of silt remain. Buff to white silt aggregates are typical of the middle part of the Hunton formation.

Shale fragments are common as residues since shales are largely insoluble. Shale fragments which are used as diagnostic of a certain

bed must be carefully distinguished from other fragments of shale which may be due to caving. Many of the shales have peculiarities such as dolocasts, casts of fossils, inclusions of pyrite or carbonaceous matter, and embedded sand grains which with the color, texture, and bedding make it possible to identify them.

Fragments of igneous rock, which were decayed but not disintegrated, were observed in several well samples. Chlorite, tourmaline, granular quartz, augite, feldspar, hornblende, and biotite were found. These occurred in a zone about 25 miles wide, extending about 100 miles northwest from the vicinity of Ada, Oklahoma. The fragments were found throughout the Fernvale and in the upper part of the Hunton formation, generally near the top of each.

SYNGENETIC

The glauconite needs no special description as its character and its origin were probably similar to those of the Tertiary greensands of the Atlantic and Gulf coasts.[10] The fossils found as residues are chiefly arenaceous *Foraminifera* and are described in another part of this study. Sponge spicules and casts of many other forms are present but have no particular significance. It is well to mention that the worm jaws found commonly in many of the equivalents elsewhere of the formations studied here are not present in the residues.

Dolocasts and chert are discussed in full under the residues derived from epigenetic constituents of the formations.

EPIGENETIC

Organisms are replaced by silica, pyrite, and glauconite, but the siliceous replacement is by far the most common. The replacements may be in the form of acicular crystalline flakes, as concentric nodular growths, vitreous quartz, or chalcedony. The nodular growths resemble siliceous oölite, but the writer has definitely identified them as replacements of organic matter by dissolving several partially replaced brachiopods which yielded the nodules.

Minute quartz crystals with well developed pyramids at both ends are commonly found. The crystals are about 0.03 millimeter in diameter and 0.1–0.15 millimeter in length. The crystals are considered as authigenic in origin[11] and occur chiefly in dolomite in quantities of less than one per cent of the original sample. Nineteen of the 20 occurrences were in the "Dense" limestone and, in this study, are diagnostic of that bed.

[10] W. H. Twenhofel *et al.*, *Treatise on Sedimentation*, Williams and Wilkins, Baltimore (1926), p. 339.

[11] P. G. H. Boswell, *op. cit.*, p. 96.

Minute crystals and fragments of anhydrite occur in the Hunton in many wells northeast of Seminole. The material is colorless and is petrographically identified as anhydrite, although that mineral is not listed by Boswell[12] as an authigenic mineral. Where found it generally occurs in abundance rather than as a few scattered crystals.

Pyrite is found in all beds and is not a diagnostic residue except where large quantities form the major part of the sample. Pyrite is often found instead of chert in the lower part of the Hunton formation where it constitutes 30–80 per cent of a total residue of 2 per cent or less. Tiny crystals of pyrite are found embedded in shale and chert. The pyrite is helpful in noting unconformities. The porous zone of the erosional surface allowed free circulation of water containing iron and sulphates during the time of erosion or facilitated such movement later. The presence of limonite has no significance except that it is related to the pyrite.

When dolomite replaces lithified limestone, crystals of dolomite are formed with cavities between them caused by a reduction in volume during the chemical change.[13] These cavities when filled by silica form a lacework of interstitial silica after the dolomite crystals are dissolved.

Siliceous oölite is not common, but it is occasionally found at the base of the Chimney Hill limestone whenever the calcareous oölite at the horizon has been replaced. The oölites are also common in the middle part of the Arbuckle limestone from 3,000 to 4,050 feet below the top of the type section along U. S. Highway 77 where it crosses the Arbuckle Mountains.

Dolocasts[14] are rhombohedral cavities formed by the solution of dolomite crystals from an insoluble matrix, such as chert, pyrite, glauconite, or shale. The term "calcicasts" might also be used if it could be determined that the cavities at one time held calcite rather than dolomite crystals. The cavities were formerly called dolomolds by the writer. However, if the crystal is considered as being the mold and the matrix as being deposited around it, then the term dolocast is preferable. The dolocastic cavities in pyrite and glauconite are on the surface and are not found within the fragment.

The dolocasts are found chiefly in chert associated with beds of dolomite (Fig. 7). The cavities may be due to the deposition of secondary chert around the dolomite crystals. They may also be due to the solution of the original crystals which were included in the silica gel

[12] P. G. H. Boswell, *op. cit.*, p. 7.

[13] W. H. Twenhofel *et al.*, *op. cit.*, p. 261.

[14] H. S. McQueen, *op. cit.*, p. 9.

TABLE I

Age		Arbuckle Mountains	Central Okla. (Subsurface)	Subsurface by Residues	S. W. Ozark Region	S. E. Missouri
Mississippian						
Upper Devonian						St. Laurent ls.
Middle Devonian	Hamilton					Beauvais ss.
	Onondaga				Sallisaw ss.	Grand Tower ls.
Lower Devonian	Oriskany	Frisco ls. / Bois d'Arc	Hunton fm.	Bois d'Arc ls.	Frisco ls.	Little Saline ls.
	Helderberg	Haragan ls. and sh.		Haragan ls.		Bailey ls.
Upper Silurian						
Middle Silurian	Niagara	Henryhouse ls. and sh.	Hunton fm.	Henryhouse ls.	St. Clair ls. (marble)	Bainbridge ls.
Lower Silurian	Alexandrian	Chimney Hill ls.		Chimney Hill ls.		Brassfield ls. / Edgewood ls. / Girardeau ls.
Upper Ordovician	Richmond	Sylvan sh.	Sylvan sh.	Sylvan sh.	Sylvan sh. (not exposed)	Maquoketa sh.
		(Fernvale) / Viola ls.	Fernvale ls.	Fernvale ls. zone 1 / Fite ls. "Dense" zone 2.	Fernvale ls. / Fite ls.	Fernvale ls.
Middle Ordovician	Trenton					Kimmswick ls.
	Black River	Simpson fm. / Bromide fm. / Tulip Cr. fm.	Simpson fm. "Dense" 1st. Dol. Seminole sd. 2nd. Dol. "Wilcox" sd.	Bromide fm. zone 3. zone 4. zone 5. zone 6.	Tyner fm. / Burgen ss.	Decorah fm. / Plattin ls.
	Chazy	McLish fm. / Oil Cr. fm. / Joins fm.	Lower Simpson	McLish fm. / Oil Cr. fm.		Joachim ls. / St. Peter ss. / Everton ls.
Lower Ordovician	Beekmantown (Canadian)	Arbuckle ls.	Arbuckle ls.	Arbuckle ls.	Cotter dol.	Powell ls. / Cotter dol. / Jeff. City dol. / Roubidoux fm. / Gasconade dol.
	Ozarkian				?	Proctor dol. / Eminence dol. ? / Potosi dol.
Upper Cambrian		Reagan ss.				Derby-Doerun dol. / Davis dol. / Bonneterre dol. ? / Lamotte ss.
Middle and Lower Cambrian						
Pre-Cambrian		Tishomingo granite			Spavinaw granite	Pre-Cambrian

before lithification. The dolocasts are remarkable for the sharp outline of the crystal form. Crystalline chert from the base of the Hunton formation in the Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., shows a few dolocasts. The cavities are from crystals of dolomite which were originally lodged between projections of the growing quartz prisms. The dolomite existed before the infiltration of the silica; the silica was deposited around the dolomite crystals. Glauconite embedded in the chert also indicates that the chert was deposited later.

Next to sand, chert is the most common residue and is of more diagnostic value. Texture, color, transparency, luster, and crystalline character are the factors which form the basis for distinguishing between the several varieties. A dark brown sucrose chert occurs as a good marker for the "Dense" limestone in the southern part of the area studied. However, a similar chert is found in a lower horizon. The microgeodic, drusy, and crystalline texture gives the appearance of aggregates of brown sugar. Another chert with a dull luster and speckled with minute limonite or pyrite granules gives a pepper-like appearance to residue from the middle part of the Bromide formation in the wells just north of the Arbuckle Mountains. Another chert of importance has a granular texture and a buff or brown color. The granules are uniform in size, composed of silt, and cemented by chalcedony. Dense, sharp, milky, opaline chert occurs abundantly, most of it probably due to the replacement of organisms.

DESCRIPTION OF ZONES AND FORMATIONS IDENTIFIED BY RESIDUES

HUNTON FORMATION

The Hunton formation, where all members are present, may be divided into three general zones on the basis of residues, and where arenaceous *Foraminifera* are present it may be divided into four zones.

The top member is identified by subsurface geologists as the Bois d'Arc limestone and is described as dense, white cherty limestone. The insoluble residues are milky white, dense chert with small amounts of sand grains and replaced organisms. The residue after solution varies from 1 to 100 per cent of the original volume, but is generally less than 10 per cent. In some places a large amount of sand produced by caving of the overlying Misener sand is noticed. The limestone is absent in most wells due to an unconformity, but occurs in nearly all wells in T. 7 N., R. 4 E.

The Haragan limestone and the Henryhouse limestone below it form the middle part of the Hunton. They are separated by a discon-

formity which is difficult to identify. Both formations are represented in the insoluble residues by varying amounts of pitted soft aggregates of silt, in places with a small amount of sand, chert, or siliceous fossil fragments (Fig. 3). The occurrence of the silt is remarkably persistent making the recognition of the Haragan and Henryhouse possible in most of the area studied. The percentage of the silt is not diagnostic since in both limestones it varies in amount from 1 to 60 per cent of the dissolved sample with an average of about 10 per cent. *Foraminifera* are rarely found in the Haragan but are common in the

FIG. 3.—Typical Hunton silt aggregates found in Haragan and Henryhouse limestones. Depth, 2,270 feet in Dixie-Norman No. 1, Sec. 13, T. 5 N., R. 4 E. (×20)

Henryhouse and, where found, make it possible to separate the two beds. In many of the wells northeast of Seminole a small sand residue prevails in place of the usual silt. The percentage of the residue is less than one per cent, indicating a limestone. In the Continental Oil Company's Allred well, Sec. 28, T. 10 N., R. 7 E., a bed 10–15 feet thick containing as much as 100 per cent chert, occurs above the silt-bearing zone. The cherty bed does not represent the Bois d'Arc but is probably in the upper part of the Henryhouse limestone. The abnormal amount of chert locally was probably deposited from the circulating ground water beneath the overlying impervious Chattanooga shale. The erosion of the Hunton before

the Mississippian has probably made it sufficiently porous for free circulation.

The thickness of the Haragan and Henryhouse in the Arbuckle Mountains varies greatly in short distances. Erosion of the Henryhouse developed a relief which makes the Haragan thin on top of the ancient hills and thick in the valleys. The residues from the subsurface samples indicate a much smaller relief and a constant thickening of the Henryhouse northeast until it merges with the Chimney Hill

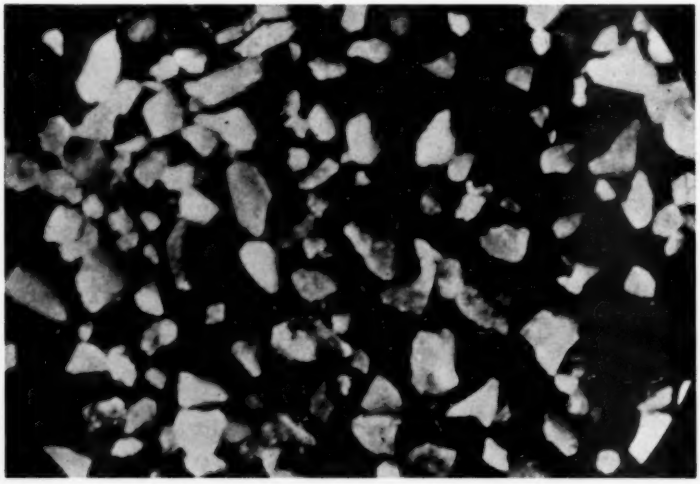


FIG. 4.—Dense white sharp chert from Chimney Hill limestone. Depth, 3,873 feet, Prairie-Palmer No. 1, Sec. 2, T. 11 N., R. 9 E.

to become the St. Clair limestone. The Haragan is thin on the subsurface section and is eventually truncated near a line from Muskogee to Okemah and Chandler.

The lowest member of the Hunton encountered in wells is the Chimney Hill limestone. The chief characteristic residues are abundant arenaceous *Foraminifera*, abundant white, dense chert, vitreous in part, and siliceous replacement of fossils (Fig. 4). The chert is usually absent in the area of the Seminole, Little River, Maud, and Earlsboro pools and the residues are composed of abundant pyrite and small amounts of sand. All residues of the Chimney Hill are generally less than 5 per cent of the original samples. Where the middle glauconitic

member of the Chimney Hill occurs, the glauconite is in addition to the usual chert or pyrite. Siliceous oölite is present in some places at the base of the limestone. Fossil replacements are common and appear as white crystalline fragments, nodules, and acicular fragments.

The beds bordering the "Seminole inlier" do not contain the typical Chimney Hill residues. The absence of the typical residue, and therefore the absence of the Chimney Hill, is considered as evidence that the uplift allowing the area to be eroded was continuous, probably coincident with the slowly rising Ozark dome. The Chimney Hill limestone was probably laid thinly across the "inlier" and eroded during the uplift and later, thus allowing the Henryhouse to be deposited in contact with the Sylvan shale in some areas and in normal contact with the Chimney Hill limestone in other areas. The remarkable similarity of some of the silt of the Henryhouse to the silt of disintegrated Sylvan shale suggests the erosion of shale as the origin for part of the Hunton silt aggregates.

The residue from the Hunton in the Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., is nearly all sand which is so similar to the sand of the Fernvale that the identification of the Hunton is impossible on that basis. The presence of dolomite crystals, which are very unusual in the Hunton, further confuses the identification. However, the typical glauconite and the crystalline chert of the Chimney Hill occur at the base of the formation and identification is thus possible. The Fernvale here is unusually characteristic so that it could not possibly be mistaken for the Hunton limestone.

The thickest section of the Hunton which has been drilled occurs in Sec. 7, T. 7 N., R. 4 E., and measures 350 feet. The Silurian portion, as defined by silt aggregates and fossils, is 250 feet thick and is chiefly limestone. The Haragan is 75 feet thick and has small amounts of chert. It is distinguished from the Bois d'Arc which has large amounts of chert. The Henryhouse and Chimney Hill limestone are 295 feet thick and the Haragan limestone only 15 feet thick in Independent Oil and Gas Company's Leclair No. 1 in Sec. 23 of the same township. The Chimney Hill, as usual, is marked by the low percentage of the residue composed of pyrite, chert, glauconite, and sand grains. The Silurian remains similar in thickness in the wells of Ts. 8 and 9 N., Rs. 2 to 7 E., although in places all of the Hunton is eroded. Wherever the Hunton is thin, it is composed of the lower beds, showing that the thinning is due to erosion. The only exception would be the area adjacent to the "Seminole inlier."

The thicknesses at the outcrops are as follows.

Formation	*Thickness in Feet*			
	Dougherty	*Franks*	*Lick Creek*	*Tulip Creek*
Frisco	—	20	—	—
Bois d'Arc	12	25	—	2
Haragan limestone	38	27	—	60
Haragan shale	95	48	10	120
Henryhouse shale	47	20	60	104
Chimney Hill limestone	22	23	12	33

The residues from the surface samples at Dougherty, Lick Creek, and Tulip Creek, along U. S. Highway 77 in the Arbuckle Mountains, may be readily recognized in the subsurface samples. The section at Dougherty has the most representative set of residues. The surface section at Franks, southeast of Ada, Oklahoma, does not show the typical residues, but the arenaceous *Foraminifera* there serve as the diagnostic element. Franks is the only place where Devonian *Foraminifera* are common. The *Foraminifera* of all the surface sections in the Arbuckles are excellent and are very useful in the subsurface study.

The St. Clair limestone in northeastern Oklahoma contains the typical Hunton silt aggregates and *Foraminifera* but in very minor quantities.

SYLVAN SHALE

The Sylvan shale is nearly 100 per cent insoluble and the bed was not studied extensively. The treated samples show gray to blue-green shale composed of fine granular silt and other fragments with layers of fine even-bedded clay. Many of the fine layers are pitted with dolocasts. A dark brown finely dolocastic shale occurs in the lower 5–20 feet. These dolocastic fragments are important as they indicate the approximate top of the Fernvale.

FERNVALE AND SIMPSON FORMATIONS

The following zones were first defined in the southern part of the area, in Pontotoc and Seminole counties. The zones may be traced northward and eastward showing gradual variation in the appearance of the residue. The same horizons could not be correlated if the gradations were not observed. Local lenses of sandstone and green shale and other variations make some zones appear different from the same zone elsewhere. These conditions should be considered when the sections are examined.

Zone 1.—Zone 1 is the Fernvale limestone, frequently called the "Viola." The top of the limestone has one of the most constant residues (Fig. 5). A few fragments of acicular white fossil replacements mixed with some of the pitted brown shale of the overlying Sylvan shale can be depended on as a marker for the top of the Fernvale except in the surface sections and adjacent wells of the Arbuckle area. The top part of the "Viola" in Peckham *et al.* Adams No. 1 in Sec. 11,

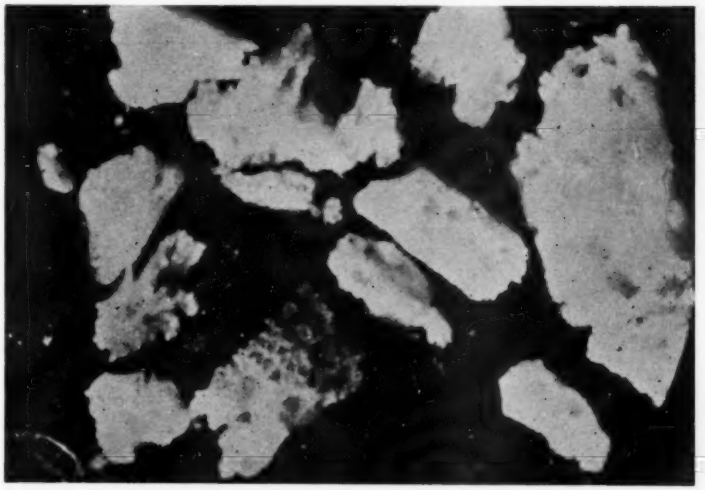


FIG. 5.—Siliceous replacement of fossils found at top of Fernvale limestone. Depth, 3,395 feet, Watchorn-Weldfeldt No. 1, Sec. 30, T. 6 N., R. 5 E. (×20)

T. 4 N., R. 1 E., contains 160 feet of dense white chert and siliceous replacement of fossils. This does not represent the Fernvale, but the middle part of the true Viola which is not found far north of the Arbuckle Mountain area. A similar situation exists in the Moore Oil Company's Wirick No. 1 in Sec. 29, T. 2 N., R. 7 E. A persistent subzone of the Fernvale with sand grains and occasional quantities of pyrite occurs 10–30 feet below the top of the Fernvale. Neither sand nor pyrite exists in quantities greater than one per cent of the dissolved sample. The sand is relatively uniform in size, 0.2–0.3 millimeter in diameter, but is variegated in character. Some of the grains show incipient enlargement, others more advanced enlargement. The grains are chiefly subangular with some frosting and occasionally secondarily enlarged grains which have been frosted.

Zone 2.—Zone 2 is the "Dense" or "Lithographic lime" as described by most subsurface geologists. The bed is 5–50 feet thick and contains 1–50 per cent residue. The characteristic residues are dense brown or drusy crystalline sucrose chert with occurrences of dense or crystalline, white and buff chert. A small amount of detrital sand is ordinarily found. A granuloid brown chert is found in some wells. Similar chert is found at other horizons in a few wells but, as a rule, the foregoing cherts are distinctive of the zone.

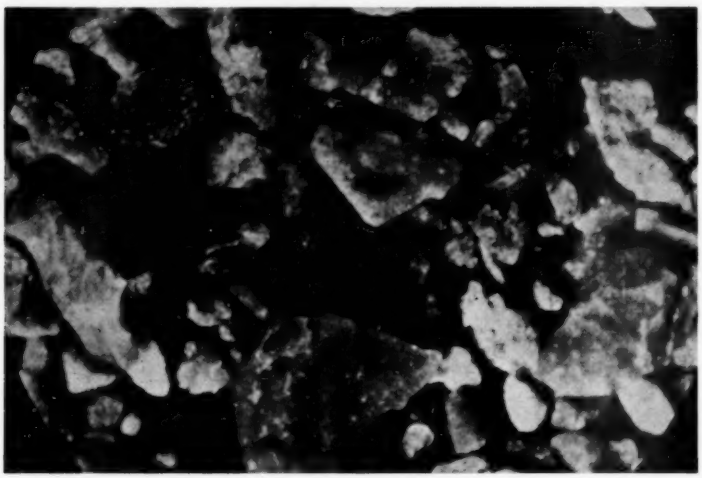


FIG. 6.—Brown sucrose chert from upper dolomite of zone 3 at top of Bromide formation. Depth, 4,098 feet, Watchorn-Zoller No. 1, Sec. 5, T. 6 N., R. 5 E. This chert also found in "Dense" of zone 2, or at top of cherty dolomite.

Minute authigenic crystals of quartz, where found, are a distinctive residue. The crystals are individual with pyramids at both ends of the prism and are 0.03 millimeter in diameter and 0.10–0.15 millimeter in length. The crystals were found in nineteen wells just below the chert horizon except in one well where they were found just below the interval for the absent chert. The "Dense" limestone is not cherty in the Independent Oil and Gas Company's Asher No. 1, Sec. 3, T. 4 N., R. 4 E., but has green shale and detrital sand similar to the Fernvale. Most of the residue northeast of T. 7 N., R. 4 E., is sand and the green shale is softer and more blue-green in color than the lower Simpson shales.

Zone 3.—Zone 3 is considered by the writer to be the top of the Simpson. It is the horizon of the upper part of the First dolomite. The horizon is markedly a zone of small residue, usually containing less than one per cent and rarely more than 5 per cent. The material is variable being composed of detrital sand, gray or green unevenly bedded shale flakes, variegated chert, or organic replacement. The zone is entirely green shale in Gillespie's Taylor No. 1 in Sec. 12, T. 5 N., R. 4 E., where 1–4 per cent shale is contained in a dissolved

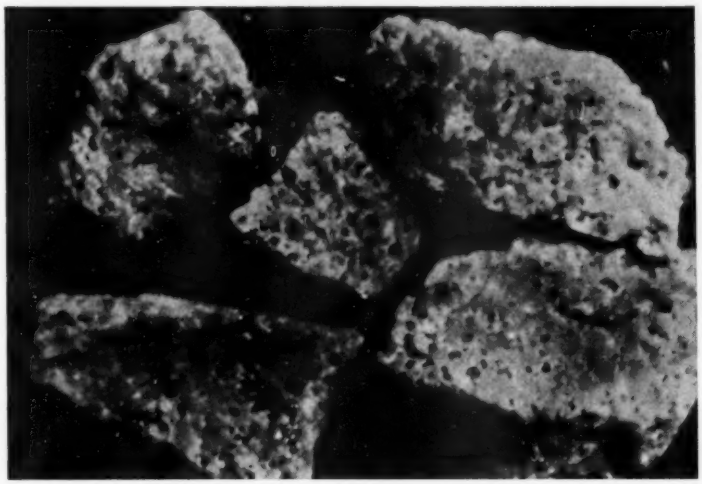


FIG. 7.—Dense brown chert with dolocasts from zone 4 in Bromide formation. Depth, 4,583 feet, Lippa-Finnigan No. 1, Sec. 11, T. 8 N., R. 4 E. (×20)

sample; however, 20 per cent shale occurs in one sample. The chief criteria for the zone are the position below the "Dense" and the small residue in contrast to the large residue of chert above and below it. The zone varies from 30 to 100 feet in thickness and lenses out northeast between zones 2 and 4.

Zone 4.—Zone 4 is characterized by large amounts of chert varying from 1 to 80 per cent of the residue, but generally having 5–20 per cent. In the wells of southern Seminole County the chert is pepperlike, lusterless, and speckled, grading laterally into white or buff, rough, weathered-appearing chert, slightly speckled. Unfortunately this zone, in many wells of the southern part of the area, also has brown drusy sucrose chert and dense, brown greasy-appearing chert similar to zone 2. However, the sequence of other residues above

generally separate it from zone 2. Dolocasts are common in this zone, both in chert and in dark brown siliceous lacework. Detrital sand of rounded frosted grains and secondarily enlarged grains occur. A few streaks of green shale also exist. The thickness of the zone is 20–150 feet with an average of 100 feet in the southern part, 50–60 feet in the central part, and less than 50 feet northeast of Seminole. It is difficult to identify this zone with only a few samples since the chert is too variable to be of diagnostic value. By the vertical, associated

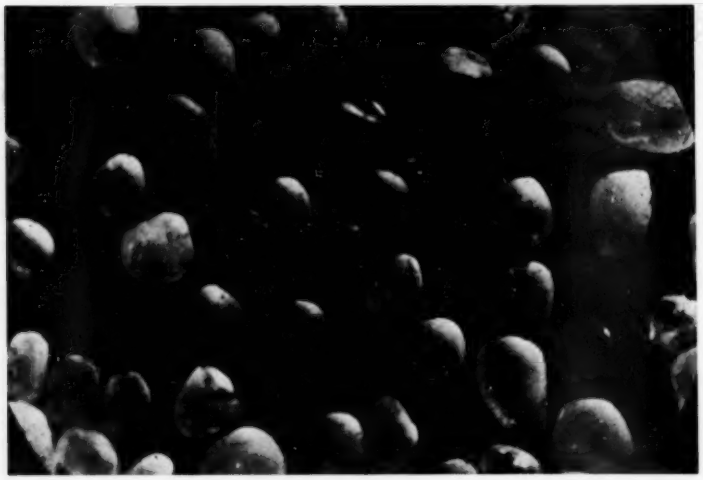


FIG. 8.—Typical, rounded, frosted, uniform sand grains of Seminole sand. Depth, 4,292 feet, Sunray-Burbonnais No. 1, Sec. 28, T. 7 N., R. 5 E. (×20)

beds, the large amount of chert, and the presence of dolocasts, the zone may be defined. This zone includes the lower part of the First dolomite and the larger part of the Second dolomite.

Zone 4 in the Seminole area may be divided into three subzones. Subzone 4a is marked by the cherty residues from the lower part of the First dolomite. The Seminole sand is subzone 4b. The cherty residue of the upper part of the Second dolomite, which is below the Seminole sand, indicates subzone 4c. The Seminole or First "Wilcox" sand is a sandstone lense 0–80 feet thick, which exists as a substitute for part of the dolomite, for where the sandstone is thicker the dolomite is thinner. The sand is not found south of Seminole County. The sand grains are well rounded, frosted, and of relatively uniform size averaging 0.2–0.5 millimeter in diameter.

Zone 5.—Zone 5 is chiefly a green shale zone with a few lenses of dolomite which have a chert residue. The shale is soapy appearing, fine-grained, and in many places has embedded sand grains of the St. Peter type, dolocasts, and fossil molds. Much of the shale is dense, hard, and fine-grained. Some of the shale is brown or gray. The samples range from a chert residue of one per cent to a shale residue of 100 per cent, showing that the zone varies from dolomite to shale. The shaly character is distinctly the dominant feature. Siliceous or-

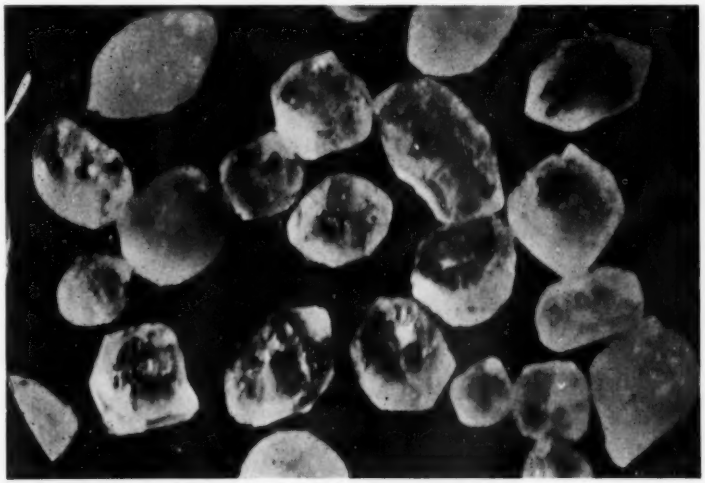


FIG. 9.—Well advanced secondary growth of quartz on large sand grains from top of "Wilcox" sand. Depth, 3,120 feet, Prairie-Fleming No. 1, Sec. 1, T. 5 N., R. 4 E. (×20)

ganisms from the dolomite beds within the zone are common and with chert form as much as 50 per cent of the residue in some samples. In such samples, however, the total residue is generally less than 40 per cent of the original sample. The thickness varies from 50 to 118 feet. The green shale zone is a marker for the underlying "Wilcox" sand. Zone 5 is the lower part of the Second dolomite.

Zone 6.—Zone 6 is the Second "Wilcox" sand. The Sinclair Petroleum Company's Gardner well in Sec. 6, T. 4 N., R. 6 E., had 625 feet of sand. Weirich[15] reports 900 feet as the maximum thickness near Pauls Valley.[16] The sand is recognized by the large

[15] T. E. Weirich, "Simpson of Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 1510.

[16] Fanny Carter Edson calls attention to the fact that the "Wilcox" thicknesses here mentioned are the two thickest sections known. "They are the exception rather

grains at the top, 0.6–1.0 millimeter in diameter, which vary from rounded frosted grains to clear angular grains in the advanced stage of secondary enlargement. Lower in the formation the grains are smaller and variable in appearance. Correlations on the basis of the sand content is hazardous. Streaks of green shale with embedded grains occur.

A peculiar type of vitreous silica was found as part of the Second "Wilcox" sand in the Tidal Oil Company's King well in Sec. 14, T. 10

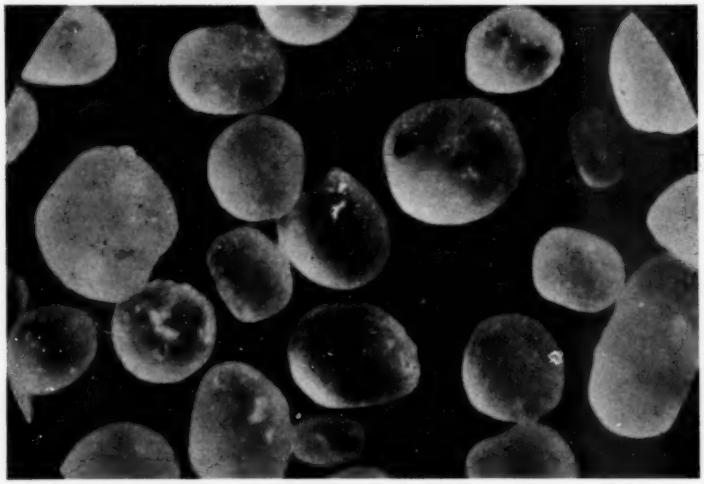


FIG. 10.—Large, well rounded, frosted sand grains from "Wilcox" sand. Largest grain 1.10 millimeters in diameter. Depth, 5,485 feet, Calcul-Wilson No. 1, Sec. 9, T. 8 N., R. 5 E. (×20)

N., R. 8 E. (Fig. 11). The fragments show clear rounded sand grains embedded in milky vitreous chert. McQueen[17] found the same type of chert in the Cotter formation of Missouri. George Rust[18] found nodular chert with sand grains embedded in the Powell formation near Weingarten, Missouri. The sand occurred in layers concentric to the

than the rule. The apparent very great thickness in these two wells (it is not all "Wilcox" sand) is probably due to exceptional, local depositional conditions. For that reason, it would be better to cite the Gypsy Oil Company's Barkus well No. 9, Sec. 6, T. 8 N., R. 6 E., to indicate the general thickness of the 'Wilcox' sand, because this well penetrated the 'Wilcox' sand (70 feet), the pre-'Wilcox' Simpson section (600 feet), and drilled 1,223 feet into the 'Arbuckle' limestone. This well, located in the Seminole region, had a normal 'Wilcox' thickness."

[17] H. S. McQueen, *op. cit.*, p. 23 and Pl. VIIB.

[18] George Rust, personal communication.

exterior of the nodule. A thin section shows sand grains of rounded quartz and some microcline surrounded by a distinct halo of chalcedony which was coarser-grained than the fine matrix of chalcedony. The haloes were circular and not parallel with the outline of the sand grain, being broader where indentations and cavities occurred. One explanation is that the sand grains were collected into balls of silica gel as the gel was moved about on the bottom during the deposition of the Powell formation. Layers of sand were added to the gel ball as it

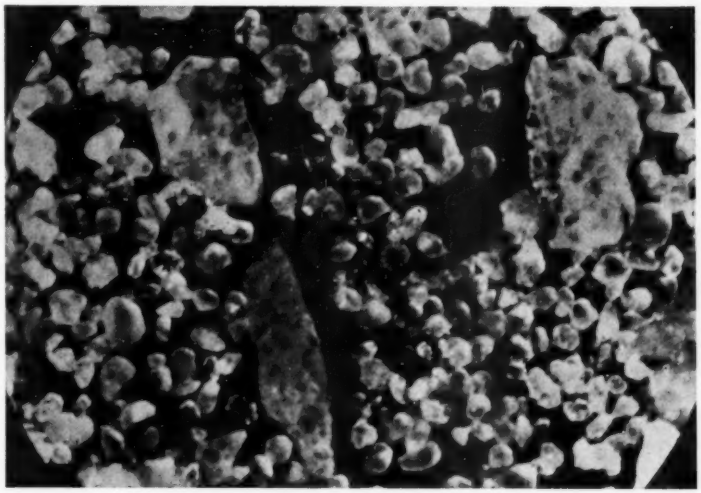


FIG. 11.—Fragments of sand cemented with milky, transparent silica associated with sand grains uncemented from Simpson formation. Depth, 4,294 feet, Tidal-King No. 1, Sec. 14, T. 10 N., R. 8 E. (×20)

grew larger by aggregation or coalescence with other silica, thus explaining the concentric banding. The type of chert is not confined to a definite horizon since it occurs in the Powell, Cotter, and Roubidoux formations of Missouri, and in the Simpson formation of Oklahoma.

In the Sinclair Petroleum Company's Gardner well in Sec. 6, T. 4 N., R. 6 E., the only well studied, which passed through the "Wilcox" sand, the sand was 625 feet thick; below it was 103 feet of green shale, then 50 feet of sandstone and shale, and at the bottom 77 feet of sandstone. It is quite probable that the Arbuckle limestone would have been encountered within the next 100 feet. These pre-"Wilcox" beds are known as the lower Simpson. The residues are all sand grains and shale fragments.

The residues of the Arbuckle limestone were studied from the Gypsy Oil Company's Barkus No. 9, Sec. 6, T. 8 N., R. 6 E., but since no other Arbuckle samples were available, the residues are not discussed. The samples above the Arbuckle were not obtainable.

CORRELATION

HUNTON FORMATION

The subdivision of the Hunton formation essentially as it exists to-day has been made by Reeds.[19] Maxwell[20] is expecting to publish new data for changes in the subdivision in the near future. The Frisco and Bois d'Arc limestones are Oriskany; the Haragan limestone is Helderberg; the Henryhouse limestone is Niagaran; and the Chimney Hill limestone is Alexandrian.

The Frisco limestone is known only at the surface in the northeastern part of the Arbuckle Mountains and near Marble City in northeastern Oklahoma. Neither residues nor lithologic features indicate its presence in wells.

The Bois d'Arc limestone is coarse-grained and cherty at the outcrop. It has a large amount of chert as a residue and is recognized on this basis where the chert overlies the typical silt aggregates of the Haragan beds below. North of the Arbuckles, dense, white, opaline chert or fossil replacement above the silt indicates Bois d'Arc, but the same residue with abundant *Foraminifera* or without *Foraminifera*, below the silt, indicates the Chimney Hill.

The Haragan and the Henryhouse are difficult to correlate separately due to their similarity. In most instances the tendency is to call the central part of the Hunton the Haragan. A lithologic study seems to show that most of the beds of the middle part of the Hunton in the Arbuckles is Haragan, but a study of the *Foraminifera* from subsurface samples indicates that the Henryhouse is the thicker there. The typical Haragan silt residue with Devonian *Foraminifera* at Dougherty can be correlated with the Haragan at Franks by means of the *Foraminifera* since the residue at Franks is not diagnostic. *Foraminifera* are rare in the Devonian, common in the Henryhouse, and abundant in the Chimney Hill. It is possible to identify the Haragan from the Henryhouse in the subsurface on the basis of the *Foraminifera*. Since the silts are common to both, no boundary can be

[19] C. A. Reeds, "The Hunton Formation," *Amer. Jour. Sci.*, Ser. 4, Vol. 32 (1911), pp. 256–68.
———, *Nat., Hist.*, Vol. 26, No. 5 (1926).
———, *Oklahoma Geol. Survey Circ. 14* (1927), p. 13.

[20] Ross Maxwell, Northwestern University, personal communication.

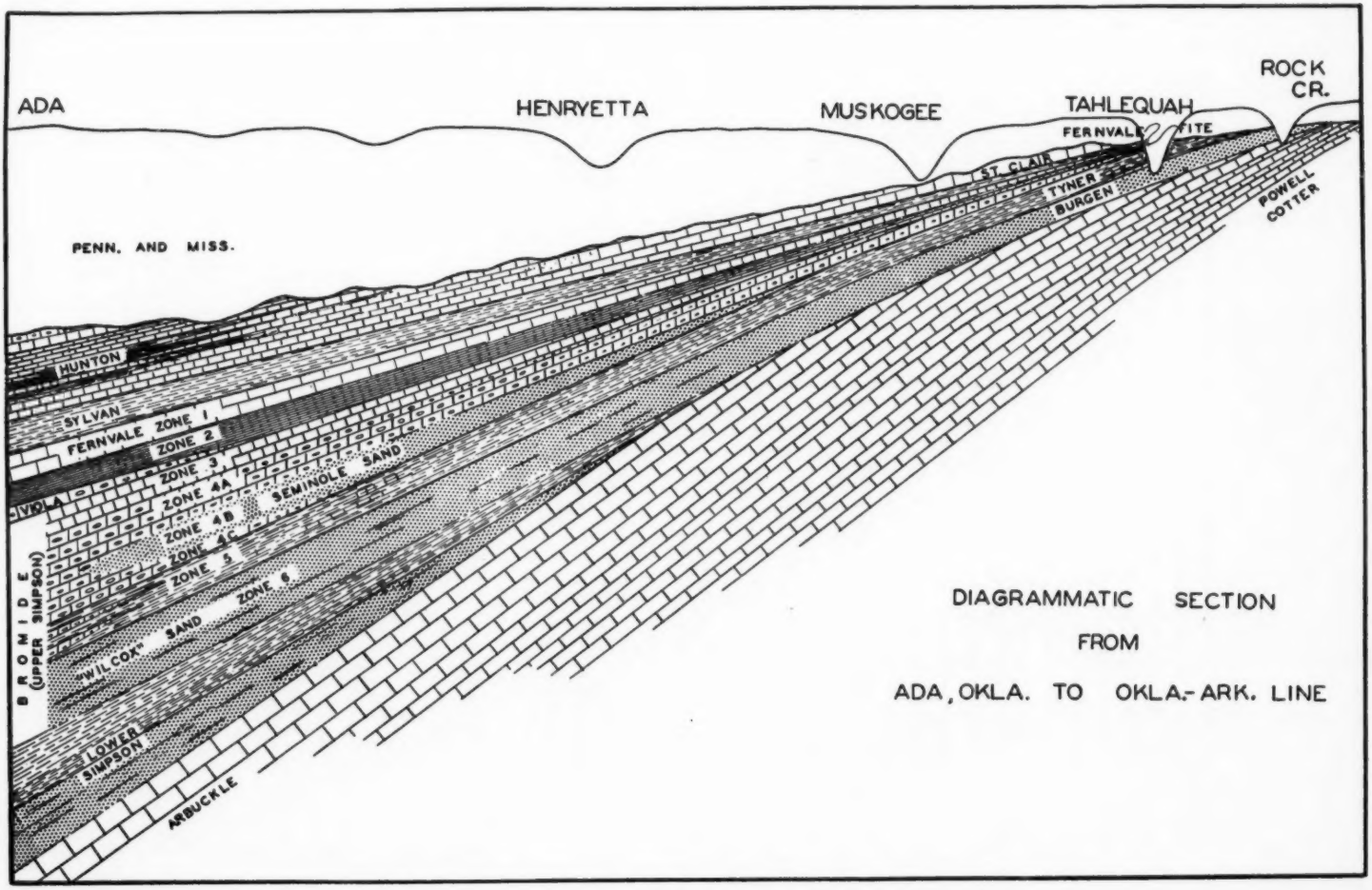


FIG. 12.—Diagrammatic section from Ada, Oklahoma, to Oklahoma-Arkansas line.

drawn where *Foraminifera* are absent. The Silurian forms are found high in the section of the subsurface which contains silt and it is concluded that the larger portion of the silt zone is Henryhouse. When *Foraminifera* are absent the same may be inferred. The Henryhouse thickens to the northward and changes laterally, as it approaches the Ozark region, into limestone with less silt. It is the writer's conclusion that the Henryhouse, by merging with the pink crinoidal member of the Chimney Hill, becomes the St. Clair pink marble of northeastern Oklahoma, where it is more than 200 feet thick. The Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., shows 160 feet of limestone with one per cent residue containing chert and glauconite at the base and Silurian *Foraminifera* 110 feet from the base. This is 25 miles from the surface occurrence of the St. Clair. The St. Clair contains fossils of Niagaran and Chimney Hill ages.[21] The arenaceous *Foraminifera* are like those of the Henryhouse and Chimney Hill. The St. Clair of Oklahoma is correlated with the St. Clair near St. Joe and Batesville, Arkansas, and with the Girardeau, Edgewood, Brassfield, and Bainbridge of southeastern Missouri. Dunn has examined the arenaceous micro-fossils of the Silurian from southeastern Missouri, and which, with the ones which the writer has found, show that the Chimney Hill and Henryhouse are the equivalent of the previously named Missouri formations.[22]

SYLVAN SHALE

The correlation of the Sylvan shale is a simple matter as the residues are 60–100 per cent gray or blue-green shale with occasional dolocasts. The brown, pitted, finely dolocastic layer at the base is a good marker for the top of the Fernvale. The Sylvan is herein called Richmond in age which is in accordance with general usage. It is equivalent to the Cason shale of Arkansas and to the Maquoketa of the Mississippi Valley.

FERNVALE AND VIOLA LIMESTONE

The residues of the Fernvale limestone ("Viola") are sufficiently constant to make it recognizable practically everywhere. The true Viola of the Arbuckle Mountains is much thicker than the subsurface sections of equivalent beds farther north due to the entrance of other beds into the middle and lower part of the section. The general surface section shows three zones. The upper 50–100 feet is coarse, crystal-

[21] Ira Cram, "Geology of Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull. 40-QQ* (1930), p. 23.

[22] P. H. Dunn, "Silurian Foraminifera of the Mississippi Basin." Unpublished thesis, University of Chicago (1932).

line, gray limestone, Richmond in age, correlated as Fernvale, followed by 400–600 feet of fine-grained, somewhat cherty limestone of Trenton age, and at the base is 200 feet of dense lithographic limestone of Black River age. The Fernvale is the limestone commonly called "Viola" in the oil fields. The bed may be traced across the state, averaging about 40 feet in thickness. It is correlated with the Fernvale outcrop northeast of Tahlequah and the Fernvale of Arkansas and Missouri.

Zone 2 is the "Dense" limestone which is considered by some as the top of the Simpson and by others as the basal part of the "Viola" of the subsurface and the basal part of the true Viola of the Arbuckles.[23] The bed is persistent and can be traced to correlate with the Fite limestone of the Tahlequah section. The thickness is 2–10 feet in central and eastern Oklahoma. The position of the Fite over the Tyner at Tahlequah seems to indicate its relation to the Fernvale above rather than to the Simpson beds equivalent to the Tyner in central Oklahoma. A fact indicating the correlation of the Fite and the "Dense" limestone with post-Trenton beds is their persistence across the state as a unit with the Fernvale while the Trenton and part of the Black River are truncated placing the Fite unconformable to the Simpson formation.

The writer made a section along the new road cut near Franks, southeast of Ada, Oklahoma. The Fernvale was found to be about 100 feet thick, the Viola 300 feet, the Bromide 150 feet, and the McLish formation below. The 200 feet between zone 3 and the Fernvale of zone 1 represents the Trenton phase of the Viola which is not found in the subsurface section except in wells close to the border of the Arbuckle Mountains. The residues of the Viola in E. H. Moore's Wirick No. 1, Sec. 29, T. 2 N., R. 7 E., Tidal Oil Company's Halverson No. 1, Sec. 31, T. 5 N., R. 2 E., and Peckham and Harris' Adams No. 1, Sec. 11, T. 4 N., R. 1 E., can not be correlated with other zones, but when viewed as the Trenton part of the Viola, they readily fit the situation. The thick cherty section may thus be correlated with the middle cherty zone of the outcrop. Zones 1, 2, and 3 thin from 400 feet in the section at Franks to 145 feet in the Empire Oil and Gas Com-

[23] A. I. Levorsen, *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 763.
Ira H. Cram, *op. cit.*, p. 21.
G. D. Morgan, "Geology of the Stonewall Quadrangle," *Bur. Geol. Oklahoma Bull. 2* (1924), p. 33.
F. C. Edson, "Ordovician Correlations in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 968.
Luther H. White, "Subsurface Distribution and Correlation of the Pre-Chattanooga Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull. 40-B* (1925), p. 17.

pany's Bonner well in Sec. 29, T. 5 N., R. 3 E., and to 120 feet in the Sinclair Oil and Gas Company's Gardner No. 1, Sec. 6, T. 4 N., R. 6 E. The decrease in thickness is caused by the disappearance of the middle Viola of Trenton age. The residues of zone 3 were found in the lower 100 feet of the Viola. The lower Black River part of the Viola is placed herein with the Bromide.

SIMPSON FORMATION

Zone 3 is considered herein as the top of the Simpson formation and as the upper Bromide. The zone is Black River in age. The upper part of the First dolomite of the subsurface section is probably the equivalent of the zone. The position of this horizon below the "Dense" limestone in the subsurface section and the position below the cherty zone of the Trenton in the surface section at Franks indicate to the writer that zone 3 is the equivalent of the Black River part of the lower Viola in the surface section.

Zone 4 is the middle Bromide and marks a distinct change in sedimentation and in residue. The zone is lithologically a dolomite but in places it has a large sand content. Levorsen states that the upper and lower dolomites which herein are included in zones 3 and 4 are indistinguishable in the southern part of Seminole County where the Seminole sand between them is absent.[24] They are easily defined by the use of residues. The zone between the top of the upper dolomite and the bottom of the lower dolomite remains relatively constant but where the sand is thick the dolomite is thin. The whole zone thins to about 50–60 feet north and northeast of Seminole with the sand occupying the major part of the zone. The Seminole sand in this area is definitely within the Second dolomite as defined by the residues. The writer is inclined to think that the lower part of zone 3 and the upper part of zone 4—that is, zone 4a—represent the First dolomite. Levorsen places the Seminole sand between the two dolomites but the residues show that it lies within the cherty zone 4. The separation by Levorsen is based on the position of the dolomites above and below the sand without regard to the cherty character. A sample log may indicate a dolomite and a cherty dolomite above the Seminole sand. According to the residues zone 4 includes the lower cherty part of the First dolomite. The chert horizon of zone 4c in the Second dolomite is not shown in the few wells where drilling has passed through the Seminole sand northeast of Seminole County. The sand of zone 4b occupies the interval, and ordinarily lies over

[24] A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull. 40-BB* (1928), pp. 27–28.

the dolomitic green shale of zone 5. The zones as recognized in the southern part of the area are not identifiable farther north than T. 9 N., but correlation is possible by tracing the changes from well to well. The residue is all sand in T. 10 N., R. 7 E., and correlation by zones is not possible. All of the Simpson thins northeast due to the sedimentation and truncation, and correlation by residues is more difficult.

Zone 5 is correlated herein with the Tyner formation of northeastern Oklahoma. The Tyner is dominantly green shale with thin dolomite layers and a very distinct dolomite bed at the top, which is correlated with zone 4. Zone 5 though dominantly green shale has much more dolomite than the surface section and is entirely dolomite in some wells. The correlations of zone 5 and the Second "Wilcox" sand of zone 6 are so closely allied that they are discussed together. There are two lines of thought which lead to different conclusions. Both concepts are influenced by the age of the Tyner formation northeast of Tahlequah and the correlation of the Seminole sand. As the sands of the Ordovician are very similar the correlation is based on relations established by residues and other evidences from lithology and paleontology.

The following correlation is derived from consideration of Cram's[25] opinion that the upper and middle Tyner are Black River and that the lower Tyner is Chazy. He states that the "Wilcox" is a bed of sand which comes in to the west at the horizon of the basal Black River. This opinion would place the upper and middle Tyner as equivalent to the Bromide, and the lower Tyner and Burgen as equivalent to the Chazy part of the lower Simpson. Therefore, according to the writer, the green shale of zone 5 would represent the upper Tyner and zone 4 would represent the thin cherty dolomite above the Tyner at Tahlequah. The lower Tyner of Cram would be correlated with the green shale below the "Wilcox" and with the green shale and dolomite of the upper McLish. The Burgen would be correlated with the basal McLish sandstone and possibly include the Oil Creek. The McLish is Chazy; therefore, the Burgen and lower Tyner would be Chazy, which would place the Burgen as equivalent to the St. Peter, if the St. Peter is accepted as Chazy in age.

The second concept regarding the correlation of the Tyner and the Second "Wilcox" sand is based on relations which the residues show in regard to the Seminole sand. Most of the wells northeast of Seminole County do not penetrate below what is called the "Wilcox" sand, that is, the "Mounds Wilcox." The writer considers that the

[25] Ira H. Cram, *op. cit.*, p. 20.

sand called the "Wilcox" is probably the Seminole sand according to the residues of the beds above and below; therefore, the "true Wilcox" should be lower. The chert of zone 4 appears above the sand and if the sand were the "true Wilcox" sand there should appear above it the green shale of zone 5 which is absent. Where wells have been drilled below the so-called "Wilcox" sand in Okfuskee, Okmulgee, and Muskogee counties, there is a green shale below the sand. The writer would call this green shale the equivalent of zone 5. Accordingly, the thick sandstone encountered below the green shale zone is the "true Wilcox" or Second "Wilcox" which is thought to be Burgen in that area as no other sandstone occurs between the green shale and the top of the Arbuckle limestone. Thus, the Burgen and the Second "Wilcox" are thought to be equivalent and if the Second "Wilcox" is definitely Bromide in age, then the Burgen is Bromide and Black River in age. All of the overlying Tyner shale must be, therefore, Black River in age. This correlation would make the pre-"Wilcox" or the lower Simpson of the southern and central part of Oklahoma lense in between the Second "Wilcox" sand and the Arbuckle limestone, and account for the green shale and sand below the Second "Wilcox." These beds would be equivalent to the McLish and Oil Creek beds of Chazy age found in the Arbuckle Mountains. The foregoing correlation agrees with Ulrich's[26] contention that the Burgen is much younger than the Chazy and that it is probably Bromide. Since Cram is uncertain about the Chazy age of the lower Tyner, the foregoing correlation is suggested. The evidence as shown by the insoluble residues is so strong in the mind of the writer that he feels the correlation should be stated.

DEPENDABILITY OF RESIDUES

Due to the variability of the residues there are only a few which can definitely be depended on as diagnostic without other evidence. The silt aggregates of the middle part of the Hunton formation are dependable but they can not be used to distinguish the Haragan from the Henryhouse limestone. The *Foraminifera* are dependable for subdivision but they are not everywhere present. The siliceous replacement of fossils at the top of the Fernvale and the glauconite and chert content of the Chimney Hill limestone are reasonably infallible residues. A section of insoluble shale is always dependable unless the bed is lenticular. If the residue was not one of the foregoing it would be difficult to take two or three samples and place them in the section on

[26] E. O. Ulrich, personal communication to Ira Cram, *op. cit.*, p. 12.

the basis of residues alone. The identification of a sample would have to be based on the percentage of the residue, recognized overlying horizons, the knowledge that underlying horizons had not been passed, and on association. The upper Hunton cherts are similar to the lower Hunton cherts. As a whole they are fresh, pure white, vitreous, milky or opaline, while the Simpson cherts are buff, brown, drusy, sucrose, mottled, lusterless, and dolocastic. Where dolocastic chert is found one may be fairly certain that the chert came from below the "Dense" of zone 2. Such chert is rarely found above zone 4. The characteristics of sand grains are of slight value as a diagnostic residue but a small amount of sand mixed with chert, green shale, or large amounts of sand would have value. Generally the Hunton has very little sand; the Viola everywhere has sand but in small amount; while the Simpson has much sand in variable quantities according to the position in the section. The peculiar variegated sand of the Fernvale and the Cotter are fairly constant, but also occur in other horizons. Organic residues alone have no significance. It should be emphasized that few single types of residues are definitely diagnostic. It requires knowledge of lateral changes, paleontologic evidence, percentage of residue, and the association of the residues to make dependable correlation.

All of the series herein studied have suffered minor movements, as the unconformities described by Edson show.[27] The beds suffered greater movement during the post-Devonian uplift and the later Arbuckle-Ouachita orogeny. These combined movements and subsequent erosion and deposition have made the sedimentation very complex. The changes in gradation all seem to occur from the vicinity of Seminole County northward. The formations thin northeastward due to truncation and greater distance from the source of sediments of areas farther south.

VALUE OF INSOLUBLE RESIDUES

The use of insoluble residues does not replace lithologic examination but is a supplement to it. Characteristics of samples which are obscured by the volume of the cuttings and by being embedded in the cuttings are liberated, concentrated, and exposed by the solution of the matrix and the diminution of the volume. *Foraminifera*, some types of chert, dolocasts, pyrite, fossil replacements, authigenic crystals, detrital igneous fragments, and silt aggregates are not commonly seen when they are embedded or mixed with the general sample.

[27] Fanny Carter Edson, "Tectonische Phasen in der Pra-Mississippi Formationen der Mid-Continent Region," *Geol. Rundschau*, Vol. 22 (1931), pp. 11–19.

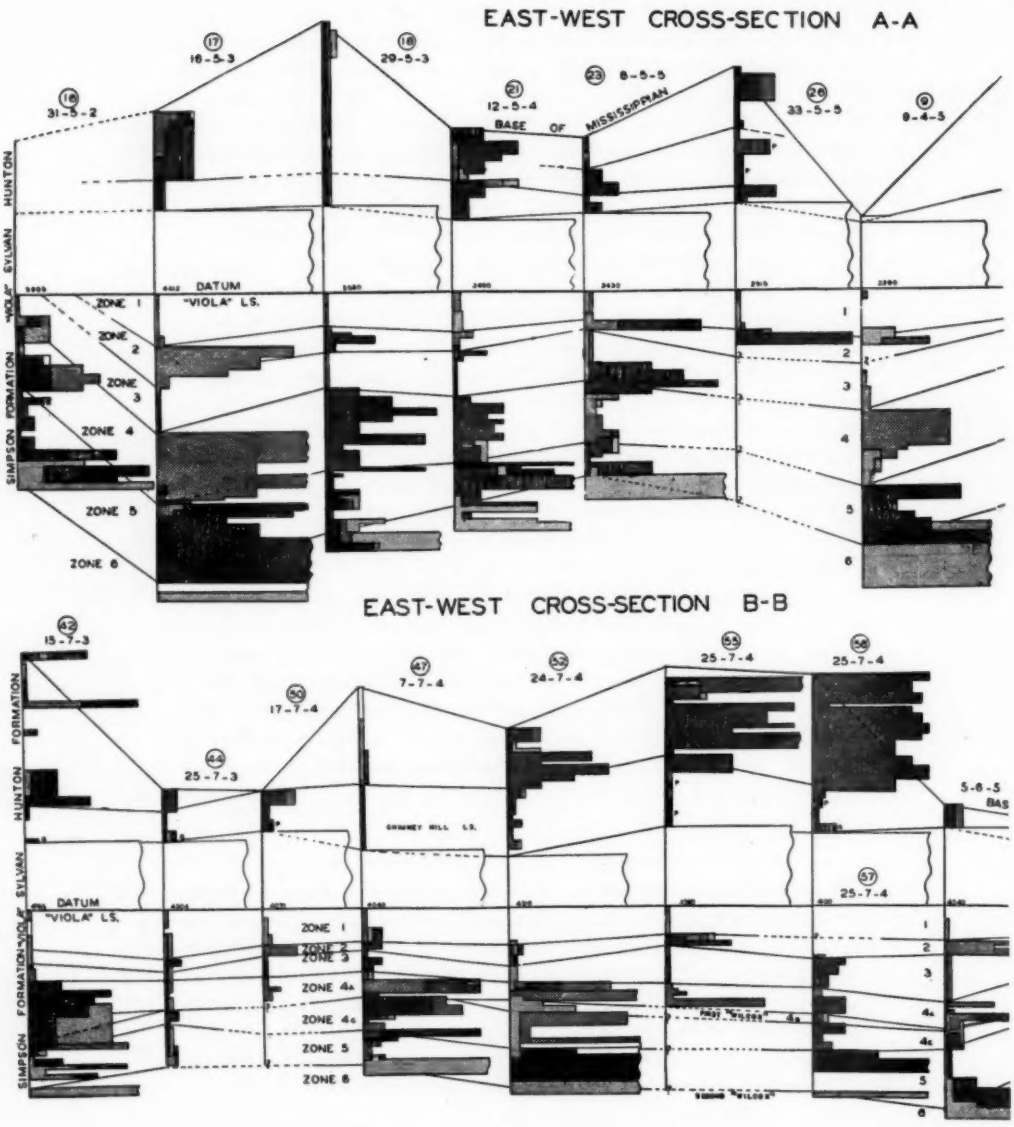
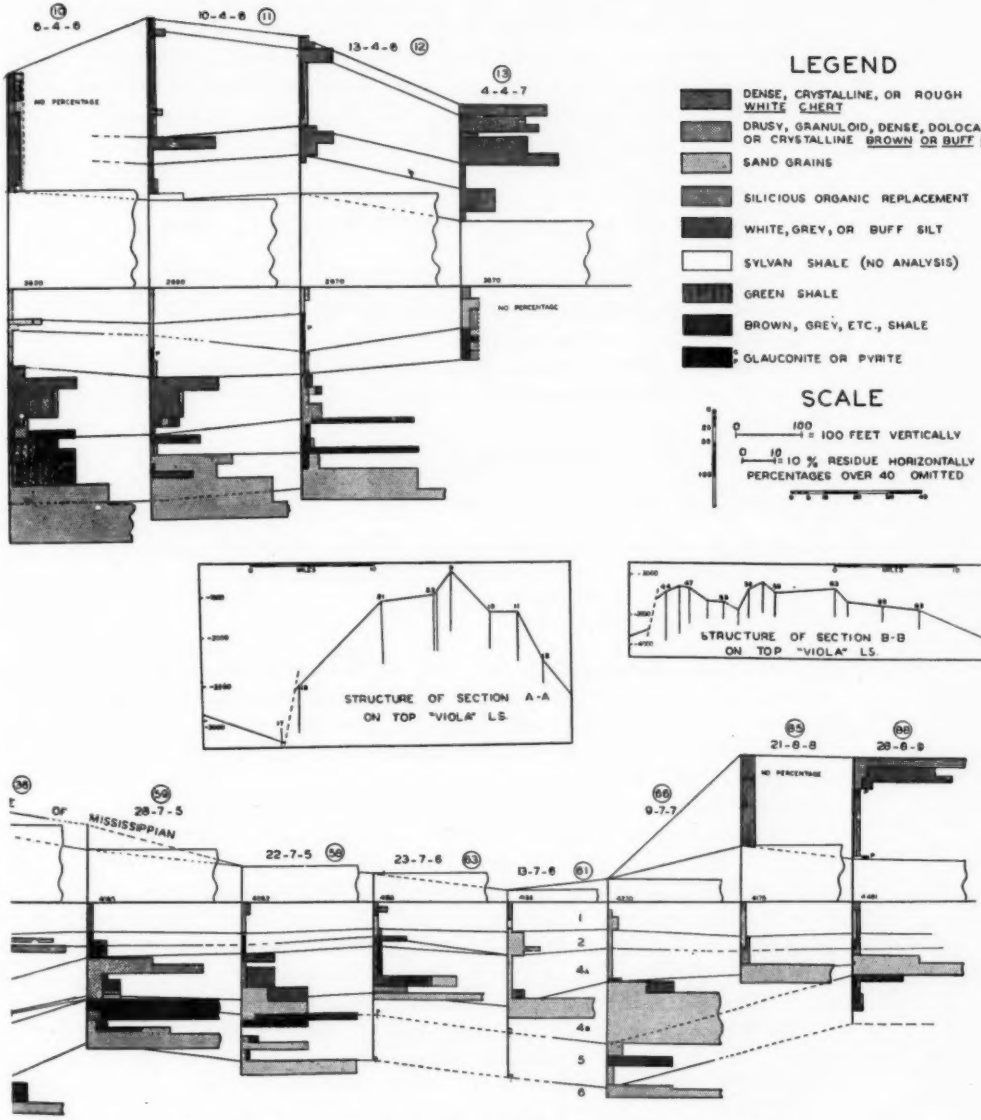


FIG. 13.—East-west cross sections *AA'* and *BB'*, showing graphic presentation of stratigraphic



correlation obtained by examination of insoluble residues. Location of sections shown in Figure 1.

Residues have value in the correction or confirmation of lithologic determination. In several instances the top of a formation established by lithologic examination has been placed 20–30 feet lower than where the residues indicate it to be. A lithologic change should be reflected by a change in the character of the residue. A small amount of sand residue at a depth of 4,435 feet in the Gypsy Oil Company's Johnson well, Sec. 7, T. 7 N., R. 4 E., changed abruptly to a residue of 5, then 20 per cent of chert. The top of the formation, as shown by lithology, was 4,455 feet. The contact might be shifted therefore up 20 feet to the point of change in residue.

The structures below the major widespread unconformity at the base of the Chattanooga shale are essentially the structures which make possible oil occurrence in large quantities. The key beds for determining such structures are limestones or well defined shales. The identification of such limestones is greatly facilitated by the use of residues.

The Fernvale limestone and the Hunton limestone may generally be distinguished but are often confused with each other even by the best geologists. White comments as follows.

> The lithologic similarity of drill cuttings from the Fernvale and the Hunton is so strong that the two are not easily distinguished on this basis. Frequently such a determination is not possible until the Sylvan shale or the Simpson formations have been identified.[28]

Levorsen[29] comments similarly. Residues are invaluable when such a situation exists. The Hunton and the Fernvale residues are so different in most places that a few samples will serve for the purpose of identification. If the distinction of these two beds was the only result of this study, the investigation would be justified. For example, if a limestone at a depth of 3,000 feet was identified as the upper Hunton, the lack of an oil-producing structure might be indicated (Fig. 14). If the same limestone was identified as the Fernvale, it might indicate a possible oil-producing structure. If the bed was determined as the lower Hunton, a structural "high" might still be indicated, but not as large a "high" as where the Fernvale was encountered. It is important, therefore, to know whether the limestone encountered is Hunton, Fernvale, or some other limestone.

The Hunton is a producing horizon in many places and it is im-

[28] Luther H. White, *op. cit.*, p. 21.

[29] A. I. Levorsen, *op. cit.*, p. 21.

portant to know if the producing bed has been encountered. The writer feels that it is possible to tell whether the sample came from the upper, middle, or lower part of the Hunton. The identification by residues would make it unnecessary to drill into the Sylvan shale before confirming the identification made from lithologic examination.

Some objection might be raised concerning the use of secondarily formed residues. Ground-water changes would tend to act more or less uniformly along the same bed unless the constituents of the bed changed or unless some local factor affected conditions. Such changes would grade away from the point of localization or from the point where the change in constituents began. Such gradations could be noted and the correlation continued. With such conditions long-distance correlation would be risky.

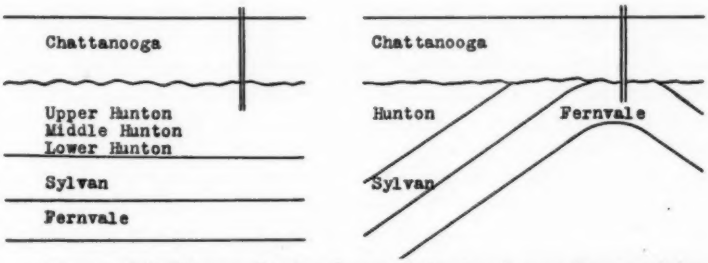


FIG. 14.—*Left.* Diagram showing absence of structure because limestone below unconformity was called Hunton. *Right.* Diagram showing presence of structure because limestone below unconformity was called Fernvale.

One of the most valuable results of this method of study is the liberation of arenaceous *Foraminifera* from the enclosing matrix. Chief dependence is generally put upon fragments of megascopic fossils or discernible microscopic fossils existing in the cuttings.

Unbroken organisms replaced with silica would have as much value as any other fossils. However, in well cuttings organisms are generally in fragments. Embryonic forms and microscopic organisms of all kinds may be used for correlation as they are too small for the drill to destroy. However, they are obscured by the volume of rock fragments unless concentrated by solution of the matrix, though at the same time many of the forms are dissolved. There is not sufficient information on the casts of interiors to make them usable. Siliceous replacement of fossils is considered merely as a type of residue rather than of paleontologic importance in this study.

Residues for long-distance correlation in Oklahoma are not satisfactory except for certain beds which have a constant residue. The Hunton formation has individual beds which have a more or less constant residue and broad distribution. The Fernvale is also recognizable but the Simpson, though it may be divided into zones which themselves are persistent, has residues which are variable and difficult to recognize unless the lateral variations and changes are carefully observed. These statements are based on the study of the Oklahoma section where strata grade laterally, are lenticular, and show alternation in composition. The fluctuating seas of the Simpson time make the sediments so variable that with the further complication of the subsequent orogenies and effects of ground-water circulation, the task of unravelling the sedimentation is colossal. McQueen has had excellent results with Cambrian and Ordovician beds in Missouri, aided by the more constant vertical and horizontal similarity of the strata studied. It is possible that the use of residues for long-distance correlation will be valuable where only general characteristics are used and where one wishes to know only the age of the bed and not a particular subdivision. Where strata of different age exist that are relatively constant in lithologic character and similar in appearance, long-range correlation may be successful as the residues may be expected also to be relatively constant. In regions in the interior of the United States, beds far from the Paleozoic coast lines should show very little gradation. Such lateral changes that do occur may be observed from a few intervening samples. For a distance of 10 miles correlations should be possible, but for 100 miles many intervening localities should be available.

The use of residues is not restricted to the laboratory. A gallon of acid and 4 or 5 tumblers may be carried along with the microscope in an automobile during field work, and if a need for a residue occurs, the material for solution and examination is available. Heat from the boiler at a drilling well or from the engine-head of the automobile may be used for rapid drying and examination made at the location.

Every stratified bed is deposited under a definite sedimentary environment and one task of the geologist is to learn of such environments. Detrital material will be deposited indigenous to the strata. If the environment changes, the detritus will be different in amount and character, and the residues will show such changes. A change in the source of the detritus would cause the residues to be different. Water circulation and changes occurring after lithification of the strata would likewise be reflected in the type of residue. These

changes, if large enough, might be observed in the lithologic examination of samples, but only the study of residues would show the small changes after the obscuring matrix has been removed.

The use of insoluble residues is limited to calcareous beds. It would be of little value to study shales and sandstones except in their relation to associated limestones. Although the Cretaceous and Tertiary beds contain abundant *Foraminifera* for correlation purposes, some of the forms are long-range and it should be possible to determine the relations of beds containing such forms more closely by the use of insoluble residues.

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GEOLOGICAL NOTES

HARDIN DOME, LIBERTY COUNTY, TEXAS

The Hardin dome, located on the east bank of the Trinity River in central Liberty County, was discovered in the fall of 1934 as a result of subsurface mapping by the writer. This structural interpretation started a development program which has resulted in the drilling of three deep tests.

The first test, J. W. Frazier's Lynott and Buffam No. 1, drilled in 1934, was carried to a depth of 7,511 feet, where it had penetrated the upper Saline Bayou formation to a depth of 102 feet. A very poor sand section was encountered in the Cockfield and those sands showing saturation also contained salt water, with the result that the well was abandoned without commercial production. This test definitely proved the presence of a major uplift.

The second test, J. W. Frazier's Lynott and Buffam No. 2, was located 1.3 miles due east of No. 1. On the upper Saline Bayou formation, it was found to have a structural position 226 feet lower than that of No. 1. At a depth of 7,661 feet, 15 feet below the top of the upper Saline Bayou formation, an oil sand was encountered and the well was completed for commercial production. From completion, it has made a large quantity of salt water which averages about 40 per cent, but in the 11 months since completion it has produced approximately 100,000 barrels of pipe-line oil and, during this period, there has been virtually no change in its flowing characteristics.

The third test, Atlantic and Brace's Hardy No. 1, commenced in March, 1936, was located 0.75 mile north and a little west of the Frazier No. 2 producing well. On what is accepted as the producing sand equivalent, it was found to occupy a very favorable structural position, being 162 feet higher than Frazier No. 2 and 29 feet lower than Frazier No. 1. The sand that is productive in the No. 2 was encountered at 7,518 feet, 48 feet below the top of the upper Saline Bayou formation. It contained salt water with a light showing of gas.

The Hardy test was drilled 640 feet into the upper Saline Bayou formation or to a depth of 8,110 feet. The Schlumberger record of the lower 560 feet of hole showed an excellent sand section and the favorable structural position of the well; it was anticipated that some of these sands should be productive. Thorough tests of the four most promising sands, however, showed nothing of commercial interest and the well was abandoned.

The peculiar distribution of oil on this outstanding structural feature is to be explained by faulting. It is known that all of the deep coastal domes are characterized by fault patterns of extreme complexity and it is a justifiable assumption that the Hardin dome is cut by a fault system that separates the south productive flank from the higher area in which the two dry holes are located. Present evidence suggests that there are two or more water levels on the dome and that, although production may not necessarily be confined to the flanks, there will be found to exist barren spots across the crest of the dome where faulting has interfered with normal fluid adjustment.

The information furnished by the development of this dome is of great importance because it will add materially to our already extensive knowledge of the complex structural types resulting from salt movement.

O. L. BRACE

HOUSTON, TEXAS
June 2, 1936

RADIO TRANSMISSION AND GEOLOGY

There has recently appeared a report on radio transmission in Ohio[1] that contains data demonstrative of correlation between effectiveness of radio transmission and geology, which will be of interest to many geologists. The report is not likely to come to the attention of geologists in the normal course of affairs, and the writer takes occasion in this brief note to call attention to it and to summarize the more important facts of geologic interest that it contains.

To the writer's knowledge this is the second time the general phenomenon has appeared with definite geologic implications. In 1934, Cloos[2] published the results of observations in which he found that broadcast reception by automobile radio fell off notably as his car crossed faults and steeply dipping contacts between different kinds of rocks. The report here cited, based on measurements of conductivity with apparatus designed for the purpose and used under controlled conditions, shows that surface geology has effects on radio transmission considerably more extensive than those noted by Cloos, and confirms his prediction that there is involved a useful geophysical principle. The radio transmission map, prepared by Higgy and Ship-

[1] R. C. Higgy and E. D. Shipley, "Radio Transmission Survey of Ohio," *Ohio State Univ. Studies, Eng. Exp. Sta. Bull. 92* (May, 1936).

[2] E. Cloos, "Auto Radio—An Aid in Geologic Mapping," *Amer. Jour. Sci.*, Ser. 5, Vol. 28 (1934), pp. 255–68.

ley,[3] which separates the state into four zones graded as to effectiveness of transmission, is a generalized reflection of the geologic map, or, rather, a lithologic map of the state. The best transmission is in the northwestern part of the state, the zone outlining roughly an area underlain dominantly by Ordovician, Silurian, and Devonian limestone. The next best zone follows a belt dominantly of shale, Devonian and Mississippian; the next, the Pennsylvanian-Permian area of coal measures, highly varied in lithologic character and containing much sandstone. The poorest zone is an area near Cleveland which probably corresponds with a large channel or group of channels buried under Pleistocene materials.[4] From these facts the generalization is obvious that radio transmission is affected by the texture of the rock immediately beneath the surface; tight, solid rock affords the best conditions and loose, open-textured materials the worst. This is supported by the fact that the values fall off notably as existing river channels are crossed, due perhaps, in part, to the topographic deflection, but probably also to the alluvium in the valleys.

Important applications of the principle in petroleum geology are not readily obvious, but they might appear in places where it is important to locate critical changes in bed rock near the surface and covered by alluvium. Possible uses in such fields as Pleistocene geology, for the location of buried channels, and in ground-water geology, are more easily visualized, and, in any event, it seems almost certain that thorough study of the phenomenon, by the methods of Higgy and Shipley under supervision of a geologist and with purely geologic ends in view, would produce results of value in some quarter of geologic science. Some time ago, when the results of the survey were first brought informally to the writer's notice, he planned such a study in coöperation with Higgy, but inasmuch as the prosecution of the plan is impossible for any time in the near future, it seems worth while to bring the existing data to the attention of geologists in the hope that further investigation may somewhere be managed.

EDMUND M. SPIEKER

THE OHIO STATE UNIVERSITY
June 13, 1936

[3] R. C. Higgy and E. D. Shipley, *op. cit.*, Fig. 7.

[4] J. E. Carman, personal communication.

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DISCUSSION

OUACHITA BOULDER PROBLEM

The writer has followed with much interest the renewed discussion on the Ouachita boulder problem, on pages 479–91 of the April number (No. 4) of the *Bulletin*. He is pleased to learn from H. D. Miser's and Philip B. King's remarks, that much new field work, supported by aerial mosaic mapping, is under way, and that a new paper on the Black Knob Ridge was presented at the Tulsa meeting of the Association (March, 1936). It would, therefore, seem premature to enter further into the discussion on the Ouachita structure, because without the much needed more detailed survey it all remains theoretization.

It may be useful, however, notably in view of W. Kramer's remarks, to point again to the great variety of structural forms that can be expected in a major orogeny, and notably within its frontal belt. That the Ouachita system, in its wider sense, is indeed one of the major late-Paleozoic mountain systems of the world is evident. Its enormous extent from Arkansas to southwestern-most Texas, and certainly beyond, is sufficient evidence.

It is by no means only the major thrustsheets that characterize such an orogenic system.

1. Particularly the frontal zone usually contains a number of slices, sheared off from the autochtonous substratum, also thrust one upon the other, but the distance these slice blocks have travelled is very small in comparison to the movement of the true thrustsheets. Also the angle of the thrustplanes is steeper. If, as in the Ouachita Mountains, there exists a notable difference in the facies of the foreland and of the geosynclinal rocks, these autochtonous slices will generally (but not always necessarily) be in foreland facies. The size and importance of such slices may be very great: in the Swiss Alps the enormous masses of the Aar-St. Gothard, and Mont Blanc-Aiguilles Rouges Massivs are in this class, protruding through the complex masses of the frontal nappes. It is possible, therefore, that tips of smaller autochtonous slices emerge within the area generally covered by thrustsheets, and also that klippen, not of sheets but of autochtonous overthrust slices, repose rootless on material belonging to a true thrustsheet (example: the Kleine Windgälle, an isolated klippe of Aar-Massiv rocks, resting on the Hochfaulen Decke, one tongue of the pack of Helvetic nappes, on the outer side of the Aar-Massiv). Such rootless klippen may either be merely pushed off, and now found not far away from the tip of the autochtonous slice from which they were sheared, or they may have adhered to the sole of a major nappe and been carried a long distance down-push from their original site.

2. A geosyncline of a major mountain system needs by no means be one single trough, exclusively filled by sediments in a uniform geosynclinal facies. Often, and there is ample evidence of this in the Eastern Alps, higher ridges may have prevailed within the geosyncline, and on these shoals or emergent islands rocks may have been deposited, which either approach or fully equal the facies on the foreland outside of the geosyncline. Overriding thrustsheets

may either have affected such preëxistent ridges in exactly the same way as they did autochtonous slices on the rim of the foreland, and have carried along klippen of apparently, but not truly, foreland rocks, now found a greater or smaller distance away toward the front of the chains.

In the case of the Ouachita Mountains it is very possible, that the Wichita-Red River chains, with rocks developed in foreland facies, might have formed a similar system of old-Paleozoic ridges and that the geosynclinal facies of the older Paleozoics might have extended also in a trough between these ridges and the true foreland. In this case the major true thrustsheets would have travelled over a substratum which contained not only foreland rocks, but also one or more intercalated troughs of geosynclinal rocks. They might have caused autochtonous slices in either facies, and the same of course applies to klippen they might have sheared off and carried along out of the substratum.

We must also bear in mind, that we do not know any of the major interior thrustsheets of the system in the exposed Ouachita Mountains of Oklahoma and Arkansas. All our knowledge is confined to the frontal belt, that is to the outer, possibly only parautochtonous nappes, equivalent to the Helvetic Decken of the Swiss Alps. Although in a Paleozoic chain, eroded far deeper into its foundations than the Mesozoic-Tertiary Alps, the outer front of these fringing nappes is no longer in existence, we must take into account that the motive power of these masses may not exclusively have been true orogenetic push, but gravitational sliding toward and into the depression of the now deepening foredeep. We also face the possibility, that major (crystalline) thrustsheets may all the same once have overridden the present Ouachita Mountains and that their *traineau écraseur* effect may have influenced structure. Subsequent erosion could have taken off these upper nappes from the presently exposed horizons.

Mere theoretical geology usually seems fairly simple at the outset, but the problems grow disconcertingly complex the moment one enters into details and tries to explain minor structures as to their place in the major plan and their detailed mechanics. The Alps, the Carpathians, and then again the Variscan Mountains, after many *decennia* of very detailed and intensive, able field work in this favorite playground of European geologists, still abound in unsolved problems of this nature. So it will be in the case of the Ouachita Mountains of America. There will remain many an outcrop, many an individual "boulder," that will baffle the ingenuity of generations to come. Happily, we have much more active drilling in America than in Europe, and it is only the core drill which can finally show what really lies under some puzzling mass of rock; we may be sure that often the outcome will prove at variance again with all our theories!

Whatever we may eventually find as to detail, the writer remains very firmly convinced, that the Ouachita Mountains constitute a frontal lobe of a major, very large system of overthrust mountains, thrustsheets of rocks, generally in geosynclinal facies, carried bodily over a substratum, in which there certainly occur rocks of the foreland (Wichita-Arbuckle) facies, but it is not necessary that in this substratum, particularly of the frontal chains, there do not occur some troughs filled with sediments of the geosynclinal facies. The majority of the so-called "exotic Ouachita boulders" are certainly sheared-off fragments of the substratum, but this does not absolutely exclude

the possibility, that here or there there might protrude the tip of some autochtonous slice, which therefore would not be a rootless klippe, but in place.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT
HEERLEN, HOLLAND
May 7, 1936

TECTONICS IN ARBUCKLE AND OUACHITA MOUNTAINS

At the annual meeting of The American Association of Petroleum Geologists held in Tulsa (March, 1936) the writer gave an informal talk on the subject of orogeny and structural trends in southern Oklahoma and the adjacent portion of Texas. Lantern-slide maps were used and a number of geologists joined in the discussion to present interesting angles of the subject, some favorable and some adverse to the ideas presented.

The essence of the theory, or interpretation, as outlined in the illustrations, was to the effect that from a tectonic point of view the Wichita, Arbuckle, and Ouachita mountains are structurally connected and inter-related. The varying sequences or facies of sedimentary rocks were recognized as well as the different periods of orogeny and diastrophism as known in modern literature. But the view was taken that orogenic pressures were so deep-seated that the resulting tectonic pattern ignored the boundaries of the sedimentary facies except by local coincidence where as a result of thrusting one facies was brought into juxtaposition with another; for example, the case in the Oklahoma salient of the Ouachita Mountains where the Ouachita facies of early Paleozoic strata has been thrust toward the northwest against Arbuckle facies. The distance of these thrust movements and the degree of variance in the original facies of deposition as well as the width of the probable horizontal transition from one typical facies to the other are points for argument and future disclosure.

The idea was presented that orogenic pressures acting in a northeasterly direction have been active through the Wichita and Arbuckle mountains to give their structural salients a northwest-southeast trend, with faulting, folding, and shortening in the Anadarko and Ardmore basins comparable with that of the Ouachita basin. During the same periods when orogeny and rock-failure produced the tectonics of the Wichita and Arbuckle areas, pressure was applied in the Ouachita area in a northwest direction thus making the structural trends northeast and southwest. Between the Ouachita salient and the Arbuckle salient there remains a hinge, or swing in the strike, which connects the two into one major structural province. Overthrusting which brings one facies of sedimentary strata against another in either the Ouachita or Arbuckle region was considered as a relatively local feature that merely interrupts the general structural continuity. However, the circumstances make it impossible to construct a map that will show the detailed connection of individual structural trends. The Cretaceous blanket obscures the details at the very point where they are most needed. The state geological map of Oklahoma is sufficient on which to apply the interpretation and test it in connection with future information from drilling.

The writer is not at serious variance with van der Gracht, Miser, and other authors who have assembled data on the various features of sedimentation, structure, and geologic history in the areas mentioned; except that he is

not inclined to accept the far-travelled nappe theory of van der Gracht. The nappe idea when applied as a more local feature is more appealing. It predicates a relatively narrow zone of original, horizontal transition of sediments between the Arbuckle and Ouachita facies of early Paleozoic rocks. The Ouachita facies is thus semi-exotic rather than having been transported from a far remote and separate basin of deposition. The position of the Ouachita sediments as they are extended across Texas is believed to correspond roughly with the original basin of deposition.

We are now learning from drilling that there is another facies of sedimentation in Ordovician strata along the Oklahoma-Texas border near Ardmore that differs from both the Ouachita and Arbuckle type. It may or may not carry a varying fauna but was apparently deposited under different circumstances than in the neighboring Arbuckle area. Limestone, dolomite, and green shale appear to take the places of black shale and sandstone. It may eventuate that fault movements will be shown to have brought different sequences into juxtaposition in that district. While he has not heard of the idea having been advanced before, the writer is of the opinion that there has been considerable longitudinal shifting along the Mill Creek syncline (fault zone), the Washita fault, and the Criner Hills fault zone. The Tishomingo anticline (fault block), the Timbered Hills anticline, and the Ardmore basin north of Criner Hills may have been shoved northwest in varying degrees of distance as a result of sliding toward the northwest during the period of late Pennsylvanian thrusting from the Ouachita area.

Regarding the orogeny of earlier Pennsylvanian time in the Ouachita Mountains and the relationships of the Arbuckle and the Ouachita facies, the question continues to arise with respect to the Johns Valley boulders and blocks. Much has been written regarding them and it is generally agreed that they represent Arbuckle facies of rocks ranging from Arbuckle limestone to Wapanucka limestone inclusive. Some of the smaller erratics are worn rounded and other large ones are in the form of blocks. The rounded ones are apparently water-worn whereas the blocks seem to have been detached from their parent mass and moved into their present position mechanically. In line with the interpretation which the writer makes with respect to the structural connection between the Arbuckle and Ouachita mountains, he has naturally drawn some conclusions on the subject of the origin and placement of these pebbles, boulders, and blocks. He does not believe that they were ice-rafted and can not reconcile the circumstances to explain the presence of rounded pebbles and boulders by postulating a drag along a thrust plane or *sole*. He believes that the evidence supports a sedimentary origin for the rounded type. But if the major faults of the Arbuckle Mountains swing into and connect with the Ouachita tectonics, as is believed to be the case, then it is conceivable that a post-Wapanucka fault scarp containing the Arbuckle facies of rocks existed in the Johns Valley sea and from it the exotics were derived. The pebbles and water-worn boulders were washed down into the sediment of the Johns Valley shale as it was deposited, the smaller ones being rather widely scattered over the sea floor. Later orogeny moved the whole mass northwest in a series of overthrusts and concealed the deep roots of the fault scarp (or scarps). Thus the immense blocks in the present Johns Valley itself, or elsewhere, would not have true roots but would connect down to the sheared-off portion of an old fault scarp the true roots of which are not dis-

closed but lie in the autochthon to the southeast. The Johns Valley shale of the Ti Valley and around the borders of the Ouachita salient was pushed north and west at the time of the late Pennsylvanian orogeny. This interpretation permits a nappe association of the blocks by mechanical transport to their present geographical position but not necessarily from a far-travelled source. The source may have been reasonably close and from strata which are rapidly transitory to the Ouachita type. Should the true roots of the Johns Valley blocks lie concealed below the thrust sheet of the Octavia fault, then the distance northwest between that point and the outer boundary of the Ouachita salient would be at least 35 miles while the distance from the large blocks in Johns Valley to the Octavia fault is approximately 12 miles.

There are certainly serious difficulties in tracing the position of such a postulated fault scarp and in defining the length, high points, and direction of hade. It would have to be an uplift of great vertical magnitude. It should be borne in mind, however, that at the west end of the Arbuckle Mountains the late Pennsylvanian orogeny and subsequent erosion permitted the Pontotoc to transgress 25,000 feet of strata from Hoxbar down to the Reagan sandstone, thus indicating the measure of total uplift in that vicinity. The earlier Pennsylvanian diastrophism was one of great intensity also at the north side of the Abuckles and in the Wichita area.

Veins of asphaltite in the Oklahoma salient of the Ouachita Mountains occupy the same belt as the Johns Valley shale. One wonders if the oil accumulations from which they resulted were not in some manner related to the period of earlier Pennsylvanian tectonics in that same geographic zone.

JAMES H. GARDNER

TULSA, OKLAHOMA
July 7, 1936

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

The Rise of American Oil. By LEONARD M. FANNING. Harper and Brothers, New York and London (1936). 220 pp. Price, $2.50.

There is a growing conviction that, with a few exceptions, authors have not laid sufficient stress upon the fundamental relations of oil to humanity. Those who have lived many years with the industry can not fail to feel that the wonderful epic story of its evolution, replete with adventure, romance, and achievement, has been too often casually passed over. So it is pleasant to pause and read the most recent of the attempts, along rather new lines, to portray its history.

Leonard M. Fanning, the author of *The Rise of American Oil*, is well qualified for thorough historical research. He was formerly director of statistics and publicity for the American Petroleum Institute. In the preface, he writes:

> The story of the rise of American oil is the story of civilization, as I see it. And that is the story I have tried to tell.

With that motif, he then proceeds carefully and sincerely to unroll the scroll of history. He shows in Chapter I, how petroleum pre-dated man and was mentioned in earliest myths, in the Scriptures, and by early Greek historians. The references and dates are familiar to all who have read Peckham and others. The awakening of civilization is described and then he traces the opening of the oil regions in Pennsylvania, with the increasing demands and scientific discoveries that led to the Drake well in 1859. By natural sequence, chapters are given to early hypotheses concerning the origin and accumulation of oil and the growth of petroleum geology.

It is admitted that this book is non-technical and is mainly intended to entertain and inform the layman. Therefore, the geologist, in common with other special lines of the industry, which are treated in the same manner, may be disappointed, because, while in general the dates and events are properly recorded, and their relation to human kind throughout all history is shown, the important details had to be passed over. Fanning has compiled and condensed into 220 pages his history of oil and civilization. The scientist and technician reader must interpolate throughout.

It is to be regretted that the index, which is credited to Miss Eloise M. Michel, has not been thoroughly prepared. For example, I. C. White's name and a few others are given but one can not refer through the index to such names as Udden and those of more ancient times, Andrews, Hunt, Logan, and Rogers, who appear in the text.

There are a few misprints which are probably due to bad proof reading. For example, Udden's name is twice misspelled; also, on pages 37 and 38, F. W. Minshall's name is misspelled three times; and this the geologist regrets, because Minshall's valuable pioneer work in Pennsylvania with his accurate barometric survey to determine structure deserves accurate credit in the history of geologic technique.

Fanning writes almost entirely in the "historical present tense." It is a question among literary critics whether the method of describing past events as if they were occurring in the immediate present is satisfactory. It can be too constantly used and if there sometimes is a lapse into the customary past historical tense, there may be some confusion in the reader's mind.

Another criticism which the dignified scientist may make is that the chapter titles are rather startling. The layman may enjoy that style but when the geologist sees a chapter describing the growth of his wonderful science of petroleum geology with the heading, "Peach Twigs and Cemeteries," he may laugh but forget the essential fact that in that chapter the growth of the science from the time of "hunches" and medicine men armed with a peach twig or divining rod is traced up to the present era. Another example is the chapter headed, "Needles in the Terrestrial Hay Stack," which treats of the speculations and research on the origin and accumulation of petroleum. In all these chapters, there are dated citations which are well worth preserving not only as reminders but for more definite references and research study.

About forty years ago, Edward Orton spoke of the great number of contributions that had been made to the literature of oil during his lifetime, and said that everyone was writing about oil but no one had fully covered the subject. True to-day. Each one of the nineteen chapters of the book herein reviewed could be built up into an interesting volume by itself.

H. B. GOODRICH

TULSA, OKLAHOMA
June 20, 1936

Down To Earth. An Introduction to Geology. By CAREY CRONEIS and WILLIAM C. KRUMBEIN. The University of Chicago Press, Chicago, Illinois (1936). 501 pp., many illustrations. Price, $3.75.

According to a paragraph on the cover flap, this text was designed for the physical science course under the New Plan at the University of Chicago and is recommended for introductory courses in geology in the first and second years of a college course. The reviewer is not conversant with the requirements of a geological text-book for Chicago's New Plan under which, according to newspaper reports, at least one student has completed the regular four years course in eight months. In *Down To Earth*, however, the departures from ordinary text-book presentation are more superficial than fundamental and, even so, are not of very great magnitude. The large type, wide spacing of lines and paragraphs, and the liberal use of black-face type and of larger type for the initial word of each paragraph give the page an appearance not characteristic of college text-books. The same methods have, of course, been in general use for many years to add to the attractiveness and readability of juvenile books, and possibly they will appeal to older readers.

Nearly all the text illustrations are small and all are unnumbered. Many are extremely simple, rather crudely drawn diagrams. Most chapters are decorated with one or two cartoons which bring back pleasant recollections of the illustrations in Bill Nye's *Comic History of the United States*. The geological cartoons, though amusing, do not seem so much in keeping with the serious tone of this book as the historical ones were with the facetious spirit

of Nye's work. The plates consist of 64 pages of rotogravure with generally 4–6 illustrations to the page, which are assembled into 4 groups of 16 pages each, distributed at approximately equal intervals through the book. Few references are made to the text figures, and most references to the plates are necessarily separated from the illustration by many pages. Perhaps this disadvantage is balanced or over-balanced by having the illustrations in position to be considered in related groups instead of as individuals.

The book is divided into 51 chapters. The first four give a general view of the earth as "a second-rate planet," its major divisions, and its "energy audit." Chapters 5–14 treat of the surficial earth processes, the agents concerned in them, and the sedimentary rocks resulting from them. Four chapters are given to diastrophism, structural geology, and earthquakes; four to vulcanism and igneous rocks; and two to metamorphism and the rock cycle. This treatment of the physical side of geology, which occupies somewhat less than half of the book, is in the same general order as that of the Chamberlin and Salisbury series of texts though differing considerably in detail.

The historical division is introduced by chapters on methods of investigations and interpretation ("Ancient History"), fossils ("Universal Cemetery"), correlation, borderlands, platforms, and geosynclines ("Older Floods"), time scale ("Gargantuan Calendar"), and mountains and climates. The history is divided into chapters on the earth's birth, pre-Cambrian, early Paleozoic events, late Paleozoic events, Permian ("An Earlier Depression"), early Mesozoic, Cretaceous ("End of an Era"), Tertiary, and Quaternary. The book follows the same plan as Charles Schuchert's *Historical Geology* in interpolating chapters on life development between historical chapters. "Life Begins" separates the pre-Cambrian from the early Paleozoic; "Invertebrate Heyday" comes between the early and the late Paleozoic; "The Forest Primeval" and "Crossing the Strand" follow the late Paleozoic; and "Medieval Life," "Megalomania" (dinosaurs), and "Cephalopods" separate the "End of an Era" (Cretaceous) from the Tertiary. "The Warm-Blooded" (birds and mammals other than primates) and "Homo Diluvii Testis" (primates) follow the chapter on the Quaternary. "Money and Politics," a 10-page review of the economic aspects of geology, and "Prospects of an End" are the concluding chapters.

The headings of many of the chapters, as are indicated in the preceding paragraph, depart from the stereotyped forms. Other attempts at lightening the subject matter are found in the frequent use of the pronouns, "we," "us," and "you." "We" and "us" mean variously the authors personally, geologists at large, and the authors and readers together. The same effort is shown in occasional paragraphs in a highly popularized style, most of which are at the beginnings of chapters. Expressions approaching more or less nearly to slang are also used sparingly and at considerable intervals. The up-to-dateness of the work is indicated by the use of the "Queen Mary" in different figures and comparisons, though the ship must have been far from completed when the text was being prepared. It is unfortunate that material which is so fresh when written becomes old stuff so soon in these days.

These variations from orthodox text-book style do not prevent the great part of the book from being good, solid geology. It seems to the reviewer that the going is rather heavy in places, for an introduction to the subject, and that the authors become apologetic for involving the reader in the more

weighty material. In one place, the reader is invited to "hang on and take a deep breath" for a plunge into deep water, and the same attitude is shown, though not expressed in the same words, in several connections.

There can be no question that the book includes sufficient material for an introductory college course in geology or for a cultural view of the subject. The informal illustrations and typography and the intimate style of presentation are, at least, interesting experiments, and they may prove to be of great value in promoting one of the aims of many geologists—the better general understanding and appreciation of the beauties which we see in our chosen science but which, we fully agree with the authors of *Down To Earth*, do not seem to possess great popular appeal as they have been presented.

L. C. SNIDER

NEW YORK CITY
June 23, 1936

Hot Oil—The Problem of Petroleum. By SAMUEL B. PETTENGILL, Member of Congress. Introduction by WILLIAM P. COLE, JR. Economic Forum Company, New York City (1936). 308 pp. Price, $2.50.

The welfare of petroleum geology and petroleum geologists is obviously dependent on the condition of the petroleum industry as a whole. Consequently, this book, though in no sense geological, should be of much interest to geologists who concern themselves in the least with the economic and governmental phases of the petroleum industry.

Under legislation proposed in 1934, and supported by a large part of the industry, federal government control of all phases of petroleum production would have been very drastic. This legislation failed of enactment by Congress and a sub-committee of the Interstate and Foreign Commerce Committee of the House of Representatives was appointed, with William P. Cole, Jr., of Maryland, as chairman, to investigate the condition of the industry during the summer of 1934. The Cole committee held public hearings at Washington, Oklahoma City, Dallas, and Los Angeles, besides making tours of the oil fields and local studies of the fields in which over-production and the problems of control were most acute. The report of the committee comprises four large volumes and an index.

Congressman Pettengill of Indiana was an interested and active member of the Cole committee and his book under review may be classified as a general summary of the investigations and hearings of the committee, which preserves the fair and impartial attitude by which the entire proceedings were characterized. The book contains 20 chapters, with a postscript and an appendix. The history of the petroleum industry and its place in our present economy are reviewed very briefly. The present condition as to proven and prospective supply, and as to over-production, is set out. The law of capture is considered in its relation to the situation and the various possible methods of obviating its evil effects are considered separately. The views of many leaders of the industry as well as views of government officials and prominent lawyers, as to the difficulties of the industry and the relative parts to be taken by the industry, by State governments, and by the Federal Government in correcting the evils of the present conditions are quoted or summarized.

Congressman Pettengill attempts no definite answer to the problems stated. In his postscript, he says:

> And so I feel accusing eyes upon me as I come to the end—"Well, what's the answer?" In my judgment, there is none except as it comes *from the people themselves*, their understanding, their common sense, their hopes for to-morrow, their needs for to-day.

He regards the problem of petroleum control as only one aspect of the broader problem with which this generation is faced and which he states in a series of questions—

> Can business men run business in the interests of the whole people? Can profits be harmonized with the needs of the nation for to-day and to-morrow? Must the states surrender their historic jurisdiction to the nation? In a word, can we secure social objectives without regimentation, prosperity without paternalism? Or, turning the question around, will paternalism produce prosperity? How much of liberty can we afford to pay for security? Or will bureaucracy in destroying liberty also destroy the efficiency and distribution of wealth which alone makes security possible? . . . What are the proper limits of the functions and agencies of the Federal Government? Those limits will be extended only as the failures of industry make the extensions seem imperative. If business seems incapable of self-discipline in the interests of the millions, government will occupy new ground. The millions will demand it and they have the votes. . . .

So far as the specific problems of the control of petroleum production are concerned, the conclusions, as indicated, are not very definite. The reviewer attended all the public hearings of the Cole committee. From the hearing as well as from the book, he believes he is safe in saying that the State compact plan was regarded by the committee as being the most promising of the solutions proposed for the hot oil or over-production problem. Also, unless the compact corrects conditions or conditions themselves change so that correction becomes unnecessary, he believes that more strenuous efforts than we have seen hitherto will be made in the direction of federal control.

To repeat Congressman Pettengill's words, though on a subject to which he has not specifically applied them, "The millions will demand it, and they have the votes."

L. C. SNIDER

NEW YORK CITY
June 23, 1936

Geology of the Tampico Region, Mexico. By JOHN M. MUIR. The American Association of Petroleum Geologists, Tulsa, Oklahoma (1936). 280 pp., 41 text figs., 15 pls., and 9 tables. 6×9 inches. Cloth. Price, postpaid: $3.50 to A.A.P.G. members and associates in good standing; $4.50 to others.

This book deals primarily with the geology of the Tampico embayment, but the author has viewed his objective with a broad perspective and presents the oil fields of that area against a background of the geologic history of Mexico. In a highly controversial field of structural and stratigraphic interpretation, the ideas of many geologists are presented and analyzed. The author then draws his own conclusions, which are logical where possible and arbitrary where data are insufficient, and he gives the reader an opinion based on long personal contact with the geologic problems of the Mexican oil fields

and on the best information available. The book is to be commended not only for the analysis and reinterpretation of earlier work, but also for the large amount of new and precise stratigraphic data which it contains. This has been obtained by the author's direct field and laboratory study and through the coöperation of many geologists who were thoroughly familiar with the conditions in certain parts of the Tampico area, and of well known paleontologists who determined the microfaunas collected by Muir.

Geology of the Tampico Region, Mexico, is an authoritative work by an expert on an area which has been one of the most important oil-producing regions of the world. The excellent areal geologic map of the Tampico embayment and the structure maps of the oil fields are significant contributions to Mexican geology. The extensive faunal lists from definite localities in each formation will be welcomed by students of earth history who seek to correlate the events in Mexico with the panorama of geologic development throughout the world.

The book begins with a brief introduction by L. W. Stephenson, of the United States Geological Survey, followed by a preface and acknowledgments by the author. Muir then divides his subject into four major parts with the following headings.

I. Introductory
II. Stratigraphy and palæogeography
III. Igneous rocks and seepages
IV. General structural features and structure of oil fields

These are followed by an appendix, a bibliography, and a list of reference maps.

Part I reviews briefly the discovery and outstanding events in the development of the oil fields of the Tampico region and describes the topography and drainage of the Gulf Coastal Plain.

Part II begins with Paleozoic rocks and gives the Mississippian and Middle Permian section of Peregrina, 11 kilometers northwest of Victoria, Tamaulipas. This is on the margin of the Tampico embayment and is the nearest outcrop of definitely determined Paleozoic sediments. A graphic sketch of the Peregrina section modified after Arnold Heim shows gneiss, at the base, overlain by Mississippian, Permian, Triassic, Jurassic, and Cretaceous strata. The gneiss is in fault contact with the Mississippian. The Triassic beds are separated from the Permian below and the Jurassic above by angular unconformities. A table and description of Liassic rocks of the Huasteca region of Veracruz and Puebla, taken from Burckhardt, show a fossiliferous marine section with some associated terrestrial plants. The Upper Jurassic is transgressive on the Lias.

Many localities in the mountains bordering the Tampico embayment, where outcrops of Upper Jurassic strata have been reported, are listed and important stratigraphic features observed at each locality are mentioned. Marine Upper Jurassic rests disconformably on Permo-Triassic red-beds at three localities in the Sierra Madre Oriental. Three wells in the Northern oil fields encountered the Jurassic at depths of 974, 983, and 1,108 meters, respectively.

The author, like most earlier writers, treats the Cretaceous as a three-fold system and discusses the stratigraphy under the European age names.

Upper Cretaceous	Maestrichtian Campanian Santonian Coniacian Turonian
Middle Cretaceous	Cenomanian Albian
Lower Cretaceous	Aptian Neocomian

Lower Cretaceous strata have been identified in two wells in the Northern fields, in outcrops in the San Carlos Mountains of Tamaulipas and in the region of Huayacocotla, Veracruz. The Middle Cretaceous is developed in two facies: a reef facies named El Abra limestone and a deep-water facies named Tamaulipas limestone. A sketch map (Fig. 5) shows the known distribution of these two facies within and bordering the Tampico embayment. Fossils which have been found in these limestones from time to time at various localities by several geologists are listed. This represents the best compilation of the faunas of the two facies which has yet appeared. Muir introduces the name Otates horizon for a shaly fossiliferous zone at the base of the Albian portion of the Tamaulipas limestone. This divides the Tamaulipas limestone into an upper and a lower division. Muir's Otates horizon is widespread in northern Mexico and has been called the Horizon of Clansayes by earlier authors. Muir names the Albian-Cenomanian beds in La Borrega canyon, Sierra Tamaulipas, as the type section of the upper part of the Tamaulipas limestone. In the Northern oil fields the Otates horizon ranges from 428 to 680 feet below the top of the Tamaulipas limestone. In two wells, at Cahuayotes and Lagartero, however, this interval is only 12 and 70 feet, respectively. Figure 11-A is an isopach map showing the variations in thickness of the upper Tamaulipas limestone.

Except at one locality Upper Cretaceous strata rest conformably on the Tamaulipas limestone wherever the contact has been studied. In most places, however, there is a disconformity between the El Abra limestone and the overlying Upper Cretaceous beds.

The author, following Stephenson, gives the name "Agua Nueva" formational rank and refers to it the beds of Turonian and Upper Cenomanian age which previous writers had designated lower San Felipe. He then limits the term "San Felipe" to beds of Coniacian and Lower Santonian age. Differential movement of the sea floor during the Turonian is probably indicated by thickening of the Agua Nueva in the synclines. There is also a regional thinning of the formation from north to south. In the Southern oil fields the Agua Nueva formation is doubtfully present.

In the subsurface of the oil fields the Agua Nueva and San Felipe formations are recognized and differentiated solely on lithologic character. Several bands of green ash in the lower part of the Agua Nueva are persistent over a large area and are used as an index bed. A lilac-colored zone of altered volcanic tuff is a distinct marker for the upper part of the lower San Felipe. The upper San Felipe in the northern fields is mainly interbedded thin beds of limestone and shale. It changes from a more calcareous facies in the north to a more argillaceous facies in the south. Layers of bentonite and tuff occur at several levels in the upper San Felipe. In the Southern fields, the San Felipe is thin

and is unconformable on the El Abra limestone. A "breccia conglomerate" occurs at the contact.

A limestone reef facies was deposited over a large area in the Sierra Madre to the west of the Tampico embayment during the period from Turonian to Campanian time. This is the Tamasopo limestone. It is, in part, equivalent to the Agua Nueva, San Felipe, and Méndez shale formations which were being deposited in eastern Mexico at the same time the Tamasopo reef was being built up farther west.

Upper Santonian, Campanian, and Maestrichtian are represented by the Méndez shale which has a thickness of about 1,000 feet in wells. Near the top of the formation 20–100 feet of the shale is characteristically red. The Méndez shales contain abundant *Foraminifera* and at several localities rudistids have been found in them. At the top is an erosional unconformity marked by irregularities in the upper surface of the Méndez and depressions filled with sands at the base of the Tamesí. Beyond the oil fields area a sandy facies of Maestrichtian age, equivalent to a part of the upper Méndez, occurs (1) in the Cárdenas-Canoas area of eastern San Luis Potosí, (2) east of Guerrero in eastern San Luis Potosí, and (3) south of Río Santa Clara in southern Tamaulipas. Thin layers of volcanic ash occur throughout the Méndez. In the Ebano oil field, thin beds of limestone are interbedded with shales from the base to within 300 feet of the top of the Méndez formation.

Transition beds between the Cretaceous and Eocene belong to the Tamesí formation and are of Danian (?) age. The author gives an excellent review and analysis of the Velasco-Tamesí-Chicontepec controversy. As no type locality had previously been designed for the Tamesí, he names an exposure on the west bank of the Río Tamesí at Tantoyuquita in the eastern part of Hacienda Naranjo, Tamaulipas, as the type. *Foraminifera* identified by Cushman from this locality are listed. The name Velasco is dropped and the Chicontepec group is Lower Eocene. South of Crucero in eastern San Luis Potosí, the Tamesí changes from a shale facies into a "flysch." The author does not specifically define his use of the term or describe the evidence for a flysch facies, other than to mention the presence of sandstones interbedded with the shales and that the strata are highly disturbed.

A summary of the Mesozoic paleogeography and an excellent composite map of Mesozoic seas (Fig. 13) are taken, for the most part, from Burckhardt's work. Epeirogenic movements are recorded at the end of the Triassic which gave rise to extensive continental deposits and to two basins of marine sedimentation: one in northern Sonora and the other in Oaxaca, Guerrero, Puebla, and Veracruz. Extensive but fluctuating seas covered much of Mexico during Upper Jurassic and Lower Cretaceous time. These were bounded by a landmass in western Mexico and by another in Texas and northeastern Mexico. In Upper Aptian (Cretaceous) time the seas transgressed northeastward across the latter landmass.

Epeirogenic movements in western and southern Mexico at the beginning of Middle Cretaceous (Lower Albian) time are reflected in central and eastern Mexico by (1) a shaly zone called the Horizon of Clansayes or Otates zone and (2) by reefs (El Abra limestone) of Middle Cretaceous age, developed on broad gentle flexures which formed submarine ridges. Middle Cretaceous seas which occupied most of eastern and southern Mexico, began to withdraw toward the close of that period. This regression was followed by a

temporary advance north and south during the Turonian, but subsequently gradual withdrawal of the sea continued throughout the Upper Cretaceous. About the close of Maestrichtian time widespread temporary emergence gave rise to the Méndez-Tamesí hiatus. Submergence during the Danian was limited by the presence of large islands in the present Gulf coastal area.

The following sequence of Tertiary formations is recognized in the Tampico embayment:

6. Túxpan formation		Lower Miocene
5. Mesón formation		Middle Oligocene
4. Huasteca formation		Lower Oligocene
3. Chapapote formation		Upper Eocene
2. Tempoal formation		Middle Eocene
1. Chicontepec Group	Unnamed beds and Aragón formation	Lower Eocene
	Tanlajás formation	

The Aragón at its type locality represents a seaward phase of the uppermost part of the Chicontepec beds and is probably equivalent in age to the Wilcox of the Texas Gulf coast. The Guayabal formation of other authors is regarded as the upper part of the Tempoal. A total thickness of about 1,600 feet of Tempoal is developed in the Tampico embayment. It is of Cook Mountain age. The Chapapote formation includes Upper Eocene strata called Alazán by earlier workers and is a seaward facies of the Tantoyuca beds.

The name Huasteca formation is proposed for Lower Oligocene beds which previously had been placed in the Alazán formation. Inasmuch as both Eocene and Oligocene strata are present at the type locality of the Alazán and as that name had been used by some authors for Eocene strata and by others for Oligocene strata, it was thought that a new name would clarify the confusion which has arisen regarding the significance of the terms. The type locality of the Huasteca formation is designated as Paso Comales where the Ozuluama-Tantoyuca road crosses the Río Comales. In the Southern oil fields the Huasteca ranges in thickness to more than 2,200 feet, overlaps remnants of Tempoal and Tamesí and in some places rests on the El Abra limestone.

The Mesón, in some places, lies conformably on the Huasteca formation and elsewhere overlaps lower horizons of the Huasteca. It includes strata which Dumble had called San Fernando and San Rafael. Upper Oligocene strata may be present north and west of Papantla, Veracruz. The Túxpan formation of Lower Miocene age rests unconformably on older horizons.

Tertiary geologic history in the Tampico embayment is one of eastward withdrawal of the sea during the Eocene, an oscillating shoreline with dominant regression during the Oligocene and Miocene. Orogenic movements in the Sierra Madre began in early Wilcox, Eocene, time and lasted until the beginning of the Miocene.

Post-Tertiary time is represented by undisturbed oyster beds close to sea-level, by caliche and coarse limestone conglomerates capping Tertiary and Cretaceous formations at higher elevations on the Coastal Plain, and by alluvium deposits as thick as 250 feet beneath the flood plains of rivers.

Part III is a brief discussion of the distribution and types of igneous rocks, recorded in the Tampico region and of the known oil, gas, and asphalt seepages. Two zones of igneous rocks are the most prominent: one east of Sierra

Tamaulipas, in southern Tamaulipas, and the other the Sierra Tantimas in northern Veracruz. The former is mostly tuffs and basaltic lavas and includes several volcanic cones; the latter consists of diorites and basaltic dikes and lavas. Cerro Bernal, near Magiscatzin, Tamaulipas, is regarded as an enormous plug pushed up 700 meters through the chimney after the formation of the lava shield. Granite blocks at the foot of the column appear to have been brought up from depth. A number of volcanic plugs occur in both the Northern and Southern oil fields. Brief petrographic descriptions of igneous rocks, by H. H. Thomas, from oil fields and from San José de las Rúsias, in southeastern Tamaulipas, are listed. Wells have encountered basalt, diorite, and in some places gabbro. Basalt is the most common type of intrusive rock. Nephelite syenite, diorite, basalt, and a variety of dike rocks occur in the Sierra San Carlos of north central Tamaulipas, and in the Sierra Tamaulipas farther south.

Seepages are grouped under three headings: asphalt seepages, oil seepages, and gas seepages. They are very abundant in both the Northern and Southern oil fields and in San José de las Rúsias on the north where no commercial wells have been developed. DeGolyer has examined hundreds of seepages and says that several thousand are present. They are characteristically associated with basalt intrusives but others occur along faults, folds, and steeply dipping strata.

Part IV presents first a general summary of the structure of the embayment and bordering ranges, followed by a detailed description of each pool or section of the Northern and Southern oil fields. This is by far the most comprehensive treatment of the famous Mexican producing fields, from a geological point of view, which has yet appeared. A good index map showing the distribution and name of the producing areas in the Northern oil fields orients the reader in following the descriptions of the pools. There is a comprehensive structure map of the Northern fields contoured on the Tamaulipas limestone and another for the Southern fields contoured on the El Abra limestone. The structure of several pools is shown in more detail in separate figures.

The Sierra Madre Oriental is a series of anticlinal mountain ranges trending north-northwest. They are commonly asymmetrical with the axial plane dipping either east or west. The eastern front of the Sierra Madre Oriental is regarded as a fold, rather than an overthrust. In that part named Sierra del Abra the fold is asymmetrical with a very steep east dip forming the mountain front of the Sierra Madre Oriental. Local faulting along this front is recognized. Overthrusting in the Sierra Madre Oriental has been mentioned by several geologists. North of Gómez Farias, Tamaulipas, five steeply folded anticlinal ranges begin east of the Sierra del Abra front and continue northward beyond Victoria. Muir states that the pressure which caused the folding came from the west, with lessening intensity eastward.

A number of smaller anticlinal ranges rise from the Gulf Coastal Plain east of the Sierra Madre Oriental. In some of these the dip of the strata on the flanks is gentle, but in others it increases to 40°. In a few ranges the normal dip has been accentuated by igneous intrusion.

The Northern oil fields are on the southern prolongation of the Sierra Tamaulipas anticline. The folding is regarded as deep-seated in origin and vertical in effect. The producing horizons are the Tamaulipas, Agua Nueva,

and San Felipe. Porosity of the reservoirs is secondary and has been induced by faulting, fissuring, and jointing of limestones. Offset wells vary considerably in the depth to production. A well situated low on the flank of an anticline may produce from a higher level than a well situated on the crest of the anticline. The rise of salt water in these fields is not a uniform advance. To December 31, 1934, the Northern fields had produced 705,800,000 barrels of oil; 4,254 wells had been completed, of which 1,483 were producers. On that date 595 wells were producing an average of 55 barrels a day per well.

The Southern oil fields are located on a buried ridge whose main deformation probably took place not later than Upper Eocene time. The arcuate trend of the ridge is divided into two parts: (1) a southern part with the northwest trend of the Sierra Madre or Sierra Tamaulipas, and (2) a northern part with a northeast cross trend. As a whole, the ridge forms an asymmetrical anticline with its steeper flank on the west. The various producing sectors of the buried ridge are separated by structural saddles or, in one place, possibly by a graben. From southern Amatlán northward, the east flank of the fold is fairly uniform, but in Cerro Azul and from Tierra Blanca southeast to Alamo the crest of the ridge is double, that is, a secondary crestal group of folds lies on the east flank. Southeast of Alamo the latter die out. The producing horizon in the Southern oil fields is the El Abra limestone. Its porosity is due to hollow fossils, solution, fracturing and faulting. The limestone is of reef origin and is formed, in part, of shell breccia. To December 31, 1934, the Southern fields had produced 986,750,000 barrels of oil. Three wells produced about one fourth of that amount, 1,002 wells had been drilled, of which 523 were producers. Production during 1934 amounted to 1,086,000 barrels from 246 stripping wells or an average of 2,975 barrels per day.

A long appendix contains data (1) on oil-field temperatures, taken largely from De Golyer's article published in 1917, (2) on well pressures, (3) on the practice of pinching production to control salt-water encroachment, (4) on shooting and acid treatment of wells, and (5) on stratigraphy obtained from well cuttings.

An excellent bibliography at the end lists 212 references.

Many geologists who are familiar with the details of certain areas or pools in the Tampico region may not agree entirely with the author's conclusions. This reviewer believes that the field evidence does not justify the statement made on page 159 that the pressure which caused the folding came from the west. He regards the eastern flank of Sierra del Abra as the front of an eastward overthrust sheet. The apparent lessening of the intensity of folding eastward in the Sierra Madre Oriental, which Muir cites as evidence for a western source of pressure, is due to release of pressure along the Sierra del Abra overthrust. That the intensity of folding does not decrease eastward is shown in the region between Guayalejo canyon and Gómez Farias, Tamaulipas, where steeply plicated folds are present east of the nearly horizontal sheet comprising the northward extension of the Sierra del Abra and Sierra Tanchipa.

On page 162 the author states that the main deformation of the Southern fields ridge probably took place not later than the Upper Eocene, though its structural features had been partly developed by the Turonian; also he states the buried ridge and the Pánuco-Sierra Tamaulipas fold have the same structural position with reference to the Sierra Madre Oriental. To the reviewer it seems that since the reef limestones of the El Abra facies are believed to have

developed on broad, gentle flexures which formed submarine ridges at the beginning of Albian time, the structural features of the Southern fields ridge began to be developed at that time. As periodic vertical uplift continued throughout the Tertiary the structure of the ridge continued to develop throughout the period. The geographic position and structure of the Southern fields ridge with reference to the Sierra Madre Oriental are so very different from the position and structure of the Pánuco-Sierra Tamaulipas fold that they should be contrasted rather than their similarity compared. The former was evidently defined as a positive area during Middle Cretaceous time, but there is no indication that the latter area was elevated before the late Upper Cretaceous. It is too broad a statement to say that the structural positions of the two folds are the same with reference to the Sierra Madre Oriental.

Another point where the reviewer disagrees with the author is in discarding the name Alazán and replacing it by the name Huasteca formation on the grounds that confusion has arisen as to its use for Eocene or Oligocene strata and because the Alazán type locality has been greatly changed by erosion. A better solution would seem to be to retain the name Alazán but to redefine it and limit it to the Upper Eocene or the Lower Oligocene and to select a new locality as typical of the Alazán (*sensu stricto*). Muir has done an admirable job in clarifying the confusion in connection with this term, but the introduction of a new name was not essential to it.

The plan of the book may be criticized for the large amount of material in footnotes and in parenthetical insertions which too frequently interrupt the reader's train of thought. The style would be more readable if there were fewer quotations and more analysis and digestion of the results of earlier work. Readers not intimately familiar with Mexican geography will find it difficult to follow the localities referred to since there is a notable lack of descriptive phrases indicating the general area in which the localities are to be found. However, a gazetteer printed with the index gives the locations of places not on the maps. In the author's effort to give a fair presentation of the views of other workers, his own interpretation is sometimes obscured. A more direct style would be more effective.

It would be curious if a scientist wrote a book having the scope of Muir's volume which other workers in the same field could accept in its entirety. In spite of certain differences in opinion regarding interpretation and style, the reviewer sees in it a wealth of material, ably assembled and satisfactorily presented. Those geologists who have worked in Mexico and contributed indirectly to Muir's volume will be gratified to see the synthesis and evaluation of their work by one who is qualified to judge. They will take pride in the canvas which he has so ably painted.

LEWIS B. KELLUM

ANN ARBOR, MICHIGAN
June 29, 1936

RECENT PUBLICATIONS

AUSTRIA

*"Austria's Future," by W. Petrascheck. *Oil Weekly*, Vol. 82, No. 2 (June 22, 1936), pp. 60–64; 2 illus. Small fields and moderate sized reserves possible.

BRAZIL

**Rochas oleigenas do Brasil e seu approveitamento* (Oil Shales of Brazil and Their Utilization), by S. Fróes Abreu. 161 pp., illus. Ministerio do Trabalho, Industria e Commercio, Instituto Nacional de Technologia, Rio de Janeiro (1936).

CALIFORNIA

*"Quarterly Chapter of State Mineralogist's Report XXXI," by Walter W. Bradley. *California Jour. Mines and Geol.*, Vol. 31, No. 4 (October, 1935). Illus., index of state reports, bulletins, and maps.

DUTCH EAST INDIES

*"Namensänderung einiger Tertiär-Foraminiferen aus Niederländisch Ost-Indien" (Revisions of Some Tertiary Foraminifera in the Dutch East Indies), by Richard E. Koch. Reprint from the report of the 15th annual meeting of the Paleontological Society of Switzerland. *Eclogae Geol. Helvetiae*, Vol. 28, No. 2 (1935).

GENERAL

Einführung in die Geologie—Ein Lehrbuch der inneren Dynamik (Introduction to Geology—A Textbook of Internal Dynamics), by H. Cloos. xii and 503 pp., 1 frontispiece, 3 pls., 356 illus. Gebrüder Borntraeger, Berlin W. 35. Price, bound, RM 24.

Lehrbuch der physikalischen Geologie (Textbook of Physical Geology), Vol. I, "Die Erde als Himmelskorper—Astronomie, Geophysik, Geologie in ihren Wechselbeziehungen" ("The Earth as a Celestial Body—Astronomy, Geophysics, Geology in Their Respective Relations"), by Robert Schwinner. xii and 356 pp., 62 figs., 1 pl. Gebrüder Borntraeger, Berlin W. 35. Price, bound, RM 16.

The Petroleum Register (New York, 1936). Southwestern Bureau, Box 1821, Tulsa, Oklahoma. Price, $10.00 postpaid. Has 846 pages with increase in listings in every section including producers, pipe lines, refineries, drilling contractors, royalty companies, *et cetera;* buyers' guide of equipment; thumb index.

*"Les flagellés fossiles aperçu biologique et paléontologique. Role géologique" (Flagellata Fossils—Biological and Paleontological Account. Geological Role), by Georges Deflandre. *Exposés de Géologie. Actualités sci. et indus.*, No. 335. 97 pp., 135 figs. Herman and Cie, 6 Rue de la Sorbonne, 6 Paris (1936).

Mémoire du Congrès International des Mines, de la Métallurgie et de la Géologie appliquée, 7 session, Paris (October 20–26, 1935). Section de géologie appliquée, 2 vols., 550 pp. each. Format, 23×28.5 cm. Price, 260 fr. belges. Office International de Librairie, 6, Rue de l'Aumônier, Liége, Belgium.

*"Petroleum Development and Technology, 1936 (Petroleum Division)," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 118. Papers and discussions presented before the division at Houston, Texas, October 10–12, 1935, and at New York, February 17–21, 1936. Published by the Institute at office of secretary, 29 West 39th Street, New York.

Acidizing Hand Book, by Benson M. Kingston. 78 pp. 5.5×8 inches.

Fabrikoid. Gulf Publishing Company, Houston, Texas. Price, $1.50, postage prepaid.

ILLINOIS

*"Research on the State's Mineral Resources and Their Utilization," Fourth annual mineral industries conference of Illinois, Urbana, Illinois, April 24–25, 1936. *Illinois Geol. Survey Inf. Circ. 16* (May, 1936). 9 pp. Abstract reports of general session, forum on researches in progress, and symposium on needed researches.

INDIA

*"Het Palaeogeen in den Indischen Archipel" (The Paleocene in the Indian Archipelago), by H. H. Badings. *Verhand. geol.-mijnbouwkundig genootschap voor Nederland en Kolonien* (Delft), Deel XI (April, 1936), pp. 233–92; 3 pls.

**Index to the Records of the Geological Survey of India, Vols. I–LXV* (1868–1932), by T. H. D. La Touche. Published by Government of India, Calcutta. Price, Rs. 6–12 or 11s.

KENTUCKY

"The Flora of the New Albany Shale: Part I, *Diichnia kentuckiensis*, a New Representative of the Calamopityeae," by C. B. Read. *U. S. Geol. Survey Prof. Paper 185-H* (1936), pp. i–ii, 149–61; pls. 30–33, figs. 9–10. May be purchased from Supt. of Documents, Government Printing Office, Washington, D. C. Price, 5 cents.

MONTANA

"The Richey-Lambert Coal Field, Richland and Dawson Counties, Montana," by F. S. Parker. *U. S. Geol. Survey Bull. 847-C* (1936), pp. i–iv, 121–174; pls. 22–27 (including maps), figs. 33–35. May be purchased from Supt. of Documents, Government Printing Office, Washington, D.C. Price, 35 cents.

PENNSYLVANIA

"Geology and Mineral Resources of the Bellefonte Quadrangle, Pennsylvania," by Charles Butts and E. S. Moore. *U. S. Geol. Survey Bull. 855* (1936). vi, 111 pp.; 12 pls. (including map), 2 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D.C. Price, 50 cents.

ROUMANIA

*"Evoluţia Geologico-Paleogeografică a Pământului Românesc" (Geological and Paleogeographical Evolution of the "Terre Roumaine"), by I. P. Voitesti. *Revista Muzeului Geol. Min. Univ. Cluj*, Vol. 5, No. 2 (1935). 211 pp., 34 figs. In Roumanian. Summary in French.

RUSSIA

*"Stratigraphy of the Gypsum and Sandy Marl Beds (Lower Red-Beds) of the North Dwina Basin," by J. T. Bogachev. *Problems of Soviet Geology* (Moscow), Vol. 6, No. 4 (1936), pp. 344–55; 1 illus. In Russian. Summary in English.

*"Tasks and Ways of the Study of Permian Deposits on the Territory of the Ukrainean S. S. R.," by O. I. Galaka. *Ibid.*, pp. 356–59. In Russian.

*"On the Question of the Present State of Gravimetrical Studies in the Caucasus," by M. A. Abakelia. *Ibid.*, pp. 360–65; 1 map. In Russian. Summary in English.

SOUTH CAROLINA

"Geology of the Coastal Plain of South Carolina," by C. W. Cooke. *U. S. Geol. Survey Bull. 867* (1936). v, 196 pp.; 18 pls. (including maps), 2 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D. C. Price, 60 cents.

TEXAS

**The Petroleum Engineer*, Vol. 7, No. 10 (July 1, 1936) is the All-Texas number and includes the following articles.

"Seventy Years of Oil in Texas, 1866–1936," by K. C. Sclater

"Texas Has Stirring History," by A. Cameron

"Petroleum Engineering Education Needs as Provided by the State," by W. D. Hornaday and J. M. Shepherd

"Review of Petroleum Development in Texas," by Joseph H. Kornfeld

UTAH

"Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," by A. A. Baker, C. H. Dane, and J. B. Reeside, Jr. *U. S. Geol. Survey Prof. Paper 183* (1936). v, 66 pp.; 26 pls. (including maps), 16 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D. C. Price, 50 cents.

"Geology of the Salt Valley Anticline and Adjacent Areas, Grand County, Utah," by C. H. Dane. *U. S. Geol. Survey Bull. 863* (1936). v, 184 pp.; 21 pls. (including maps), 4 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D. C. Price, $1.00.

"The Book Cliffs Coal Field in Emery and Grand Counties, Utah," by D. J. Fisher. *U. S. Geol. Survey Bull. 852* (1936). iv, 104 pp.; 15 pls. (including maps), 2 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D. C. Price, 75 cents.

"Geology of the Monument Valley-Navajo Mountain Region, San Juan County, Utah," by A. A. Baker. *U. S. Geol. Survey Bull. 865* (1936). vi, 106 pp.; 17 pls. (including maps), 3 figs. May be purchased from Supt. of Documents, Government Printing Office, Washington, D.C. Price, 60 cents.

VENEZUELA

*"Tertiary Plants from Venezuela," by Edward W. Berry. *Proc. U. S. Nat. Mus.*, Vol. 83, No. 2988, pp. 335–60; 4 figs., 1 table.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 4 (June, 1936).

"A Contribution to the Phylogeny of the Orbitoidal Foraminifera, with Descriptions of New Forms from the Eocene of Mexico," by R. Wright Barker and T. F. Grimsdale.

"*Helicolepidina nortoni*, a New Species of Foraminifera from a Deep Well in St. Landry Parish, Louisiana," by Thomas Wayland Vaughan.

"New Species of Orbitoidal Foraminifera of the Genus *Discocyclina* from the Lower Eocene of Alabama," by Thomas Wayland Vaughan.

"Blastoids of the Osage Group, Mississippian: Part I. The Genus *Schizoblastus*," by L. M. Cline.

"Lower Mississippian Micro-Crinoids of the Kinderhook and Osage Groups of Missouri," by Raymond E. Peck.

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1934," by Hans E. Thalmann.

"New Name for a Morrison Ostracode Genus" (Paleontological Note), by C. C. Branson.

**Journal of Paleontology* (Fort Worth, Texas), Vol. 10, No. 5 (July, 1936).

"New Silurian Brachiopods of the Family Triplesiidae," by E. O. Ulrich and G. Arthur Cooper.

"New Brachiopods and Trilobites from the Upper Ordovician of Percé, Quebec," by G. Arthur Cooper and Cecil H. Kindle.

"Cephalopods from the Upper Ordovician of Percé, Quebec," by August F. Foerste.

"Ordovician Graptolites from Quebec and Tennessee," by Rudolf Ruedemann.

"A Suggested Nomenclature for the Cusps of the Cheek Teeth of Rodents," by A. E. Wood and R. W. Wilson.

"A New Rodent from the Pliocene of Kansas," by Albert Elmer Wood.

"The Nemestrinidae of the Miocene of Florissant, Colorado, and their Relations to the Recent Fauna," by Joseph C. Bequaert and F. M. Carpenter.

"Data on the Relationships of Local and Continental Mammalian Faunas," by George Gaylord Simpson.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 8 (AUGUST, 1936), PP. 1146-1148

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 20, NO. 8 (AUGUST, 1936), PP. 1149-1152

Memorial

JAN VERSLUYS (1880–1935)

Versluys studied at the technical university of Delft in Holland and at the École Nationale Supérieure des Mines in Paris. He graduated as a mining engineer from Delft in 1905 and obtained a doctor's degree at the same university in 1916.

In 1907 he began his career in the Government Mining Service in the East Indies, where he continued until 1912. Initially his work was especially connected with hydrological problems and soon he attracted attention by the publication of some excellent papers on the theory of ground-water movement and reservoir strata. During the years 1912–1914, he executed several commissions on behalf of private mining and petroleum enterprises in India. He returned to Europe in 1914 and accepted a leading scientific position at the Government Bureau of Hydrology at the Hague (Ryksbureau voor Drinkwatervoorziening). During 1918 and 1919 he also taught hydrology at Delft. In 1919, he again went to the East Indies where he remained until 1924, this time as director of the municipal water-works of the city of Soerabaia (Java). He continued to publish a great number of highly appreciated technical papers on hydrological subjects and related problems. After his return to Holland in 1924 he again taught practical hydrology at Delft. In 1926 he was elected a member of the Royal Academy of Sciences of the Netherlands. In 1927 he was sent on a special Government commission to the West Indies, to advise on planned water-works in Curaçao and in Dutch Guyana (Surinam).

His extensive theoretical research work on the underground movement and accumulation of water led him to similar studies on the movement and accumulation of oil and gas in sediments. In 1927 he entered the service of the Bataafsche Petroleum Maatschappy (Royal Dutch-Shell Group) at the Hague in an advisory capacity. In 1932 he was appointed professor of economic geology and mineralogy at the University of Amsterdam. Here his course on the genesis of petroleum attracted considerable attention; he was very appreciative of American research work (by Trask *et al.*) and similar work in Russia. His numerous publications show how his original studies on theoretical hydrology branched out into such subjects as ground movements in quicksands (1926), subsidence caused by mining operations (1927), the compaction of sediments, and, from 1928 on, subjects dealing with much orginal research on oil and gas engineering problems, as pressure and potential energy of gas in oil-bearing formations, principles of gas lift, mathematical theory of flowing oil wells, water flooding and edge-water encroachment, oil and gas migration, well spacing, the jamin effect, *et cetera*. His work for the Royal Dutch-Shell was of a pioneering character in their organization, where he may be said to have created a new school of theoretical oil engineering and to have contributed a number of original ideas on problems connected with modern production. His sound theoretical ground-work has been the starting point of much practical application of the highest utility.

Versluys' generally regretted death occurred on March 1, 1935, at the age of only 55 years. His demise was a serious loss to science and to his numerous appreciative friends and pupils.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT

HEERLEN, HOLLAND
May, 1936

KARL ETIENNE YOUNG

The death of Karl Etienne Young on April 20, 1936, robbed The American Association of Petroleum Geologists of one of its well known members. His appropriate knick-name "Happy" was familiar to everyone in the oil business. His death came as the result of an accident at an oil well a short distance from Houston. An air compressor exploded driving a large piece of metal completely through his chest, piercing his left lung. He was hurried to Houston by two of his associates, Ben Journay and George Byrne. Blood transfusions were administered, and he staged a valiant fight for his life for more than two weeks before succumbing.

Born on October 11, 1903, at Centreville, Louisiana, he was of German ancestry on his father's side and French ancestry on his mother's. His grandfather Jacob Jung came to this country and settled in New York, marrying Margaret Stultz, an emigrant from Wurtemburg, whose father had been a soldier in Napoleon's army during the Russian campaign. The spelling of the family name was changed to Young. Jacob moved to New Orleans in 1871 and was followed by his family in 1874. In 1878 they moved again, to Week's Island, and the family has maintained its home in the Bayou Teche country ever since. Happy's father, Will J. Young, for years was a prominent farmer at Centreville, though more recently making his home at Baldwin. He is well known in Louisiana for his efforts in behalf of education. His mother, Amy Etienne, died June 28, 1927. According to family traditions, Happy was descended through her side of the family from Etienne Lafitte, a famous early Louisiana character. Happy was the seventh of nine children: Mrs. Pearl Hay, Mrs. Eugene Peltier, Mrs. Mamie Daigle, William, Mrs. Lena DeGrummond, Mrs. Alma Peltier, Karl Etienne, Lee, and George. The youngest of his brothers, George, was associated with him in his business at Houston.

After making an exceptional record in high school, Happy entered Louisiana State University in the fall of 1920 as a freshman in agriculture. He changed his course of study to geology in 1922, obtaining his degree in 1924, as one of the three first graduates of the School of Geology. He remained an additional year, serving as an assistant, spending a part of his time in Shreveport, where he accompanied W. C. Spooner on a number of his field trips to study the interior salt domes of Louisiana. Undoubtedly Spooner's advice was of much help to him in later years. While a student at the university he took a great interest in athletics, serving as student manager. He was a charter member of the Louisiana section of the Geological and Mining Society of American Universities, was a member of the local social fraternity, Theta Kappa Beta, and because of his scholastic record was elected to membership in Phi Kappa Phi.

On leaving the university he was employed by the Rycade Oil Corporation, Houston, Texas, as paleontologist from June, 1925, to October, 1927. He became chief geologist of the Rycade during his employment, serving as

KARL ETIENNE YOUNG

chief until June 1, 1929, when he became chief geologist of the Union Sulphur Company and Calcasieu Oil Company, Sulphur, Louisiana, a position which he resigned six months later to open consulting offices at Baldwin, Louisiana.

Moving to Houston in September, 1930, he opened an office in the Mason Building. The following year he joined the firm of Fisher and Lowrie, an association which lasted until Lowrie's retirement from active practice in March, 1935. From 1935 until his death he was associated with J. Garfield Buell of Tulsa. Through his efforts, Gas Power Incorporated was organized in December, 1934. Associated with him in this enterprise was G. O. Nevitt of Houston, his brother, George Young, one of his college associates, Warren Jackson, and a number of younger men from Louisiana State University and from Texas.

During all the years he spent in Houston, Happy lived at the home of Mrs. Jim McIntyre, 4832 Caroline Street. This address became famous with Louisiana State graduates as there were always a number staying there, and Happy always made it a practice of finding a place there for the boys just finishing school until a job could be located. His life and deeds have proved an inspiration to scores of graduates of the School of Geology, a large part of whom he helped to get started in the oil business.

Happy lived solely to be of help to others. He had a long and successful record with the Boy Scout movement in Houston. He served as a scout, assistant scout master, scout master, and district commissioner. His scouting days were spent in Centreville, Louisiana. He was scout master of Troop 32, Houston, later commissioner of District 5. He served in 1930 and 1931 as camp director of the Houston Area Council's winter camp at Camp Hudson, and was active in the summer camping program. He was interested in the formation of Boy Scout troops in the oil-field camps. He was personally responsible for the formation of four Boy Scout troops in Louisiana, and was responsible for the formation of the first Boy Scout troop in an oil-field camp in Texas. This troop was organized at Raccoon Bend, near Bellville, with the assistance of W. J. Jackson and local leaders. In addition to his scout work, he was the organizer and director of the Cherryhurst Athletic Club, and was a member of the Scoutmasters Association of the Houston Area Council, where he served as an officer.

Being very modest, no one will ever know how many young men he helped obtain a college education, but the number was great and he always took intense pride in their accomplishments. While not given to writing articles, he contributed freely to others from his store of scientific information. He became a member of The American Association of Petroleum Geologists in 1926, and was a charter member of the Society of Economic Paleontologists and Mineralogists.

HENRY V. HOWE

BATON ROUGE, LOUISIANA
July, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

RALPH ESAREY has been appointed State geologist of Indiana, succeeding WILLIAM M. LOGAN, retired.

WALTER E. HOPPER, petroleum valuation engineer with the Securities and Exchange Commission of Washington, D. C., was in the Mid-Continent region in June.

ANDREW COWPER LAWSON, professor of geology, emeritus, at the University of California, will be one of 66 of the principal speakers at the Tercentenary Conference of Arts and Sciences, upon whom Harvard University will confer an honorary degree on September 18.

DILWORTH HAGER, consulting geologist, Dallas, Texas, addressed the Oklahoma City Geological Society, June 8, on the faults of northeast Texas and the Talco fault system.

PAUL D. TORREY addressed the Houston Geological Society at a luncheon, June 11, on the salt anticlines in southern New York state.

WILSON KEYES, 35, consulting geologist and operator, Midland, Texas, was instantly killed, June 6, in an automobile collison. E. S. MCLAUGHLIN, consulting geologist, who recently moved from Wichita Falls to Midland, was a fellow passenger and received serious injuries.

CARL BEAL, RUSSELL HAVENSTRITE, S. B. MOSHER, and others, of Los Angeles, have formed the Iniskin Drilling Company and plan to drill a deep test near Iniskin-Chinitna Peninsula, Cook Inlet, 180 miles from Anchorage, Alaska.

KENNETH L. GOW, Superior Oil Company, Bakersfield, California, has been transferred to Shreveport, Louisiana, where his address will be 1613 Slattery Building.

GLENN GRIMES, chief geologist of the Cromwell-Franklin Oil Company, has resigned that position and is now a consulting geologist at Oklahoma City.

JOSEPH S. IRWIN, consulting geologist, Calgary, recently addressed the Oil and Gas Shareholders Association in that city on "Some Facts and Fallacies Concerning the Oil Industry."

GENTRY KIDD, geologist for the Stanolind Oil and Gas Company, has been transferred from Amarillo to San Antonio, Texas. W. E. HENDERSON is being transferred from Shawnee, Oklahoma, to fill the vacancy at Amarillo.

HAROLD A. SACKMAN has changed his address from McAlester, Oklahoma, to 609 North 22nd Street, Fort Smith, Arkansas.

P. HASTINGS KELLER has changed his address from Lansing, Michigan, to J. V. Wicklund Development Company, Mortgage and Bond Building, 5 Larned Street, West, Detroit, Michigan.

HARRY X. BAY has changed his address from the Illinois Geological Survey, Urbana, Illinois, to 216 College Street, Sulphur Springs, Texas.

WILLIAM B. MOORE, formerly with the Shell Petroleum Corporation, Houston, Texas, is now with the Atlantic Oil Producing Company, Esperson Building, Houston, Texas.

C. H. DRESBACH has been transferred from the Mexican Gulf Oil Company to the Gulf Research and Development Company, Box 2038, Pittsburgh, Pennsylvania.

SYLVAIN PIRSON has been made assistant professor in charge of petroleum engineering at Pennsylvania State College. His address will be Petroleum Engineering Department, Pennsylvania State College, State College, Pennsylvania.

T. R. ESKRIGGE, geologist for the Gulf Oil Corporation, has been transferred from Pittsburgh, Pennsylvania, to Lake Charles, Louisiana (Box 881).

S. R. SAY, formerly field geologist with the Transcontinental Petroleum Company, Tampico, Mexico, may now be addressed at 4803 Montrose Boulevard, Houston, Texas.

LEAVITT CORNING, JR. has resigned from the Plymouth Oil Company, where for the past four years he has been connected with the geological and magnetometer department, to enter the independent field as a consulting geologist and magnetometer operator. His offices will be in the Milam Building, San Antonio, Texas.

DORSEY HAGER and GRENVILLE HOWARD of the firm Hager and Howard have opened offices at 601 Union Trust Building, Winnipeg, Canada. Hager will continue to make his headquarters at 808 Olds Tower Building, Lansing, Michigan, and the Canadian office will be in charge of Howard. They will specialize in examination, appraisal, and exploration of petroleum and natural gas prospects and natural gas engineering.

ALAN BRUYERE, formerly with The Texas Company, Fort Worth, has been transferred to Houston and is working in the geophysical department of the company. His new address will be Box 2332, Houston.

DJEVAD EYOUB, petroleum engineer who has been directing exploratory drilling for the Turkish Government, will henceforth be known as CEVAT E. TASMAN, in compliance with a new Turkish law requiring everybody in the country to adopt Turkish family names.

KURT H. DECOUSSER of the exploration department, White Star district of the Socony-Vacuum Oil Company, Incorporated, has changed his address to 1621 Drexel Road, Lansing, Michigan. A daughter, Denise, was born to Mr. and Mrs. deCousser on March 5.

G. S. RICE of the Edgar Tobin Aerial Surveys, San Antonio, Texas, ad-

dressed the Dallas Geological Society, June 16, on "Air Mapping Found Valuable in Surface Work."

E. B. OBERING, district geologist for the Shell Petroleum Corporation at Midland, Texas, delivered a paper entitled "A Review of Salt Deposition in the Permian Basin," at the meeting of the West Texas Geological Society, Midland, June 20.

JOSEPH E. PURZER, geologist for the Phillips Petroleum Company, has been transferred from Midland, Texas, to Shreveport, Louisiana.

On Friday, June 12, a group of geologists stationed with the various companies at Lake Charles, Louisiana, met at a luncheon in the Majestic Hotel to discuss the forming of a society for the South Louisiana district. The following officers were elected: R. B. GRIGSBY, Stanolind Oil and Gas Company, Lake Charles, Louisiana, president; C. IVAN ALEXANDER, Magnolia Petroleum Company, Lake Charles, vice-president; JAMES S. KIRKENDALL, Amerada Petroleum Corporation, Lake Charles, secretary; C. B. LOVE, Shell Petroleum Corporation, Iowa, Louisiana, treasurer. It was decided to hold bi-monthly meetings on the first and third Mondays of each month.

W. ARMSTRONG PRICE has recently published an article, "Does Static Electricity Cause Autoignition of Wild Wells," in *Mining and Metallurgy*, Vol. 17, No. 353 (May, 1936), Section 1, pp. 240–42; 2 figs.

W. L. GRAHAM has recently accepted a position with W. A. DELANEY and may be addressed at the W. A. Delaney Building, Ada, Oklahoma.

OLIVE HOFFMAN, micropaleontologist with Phillips Petroleum Corporation, Wichita, Kansas, is taking a 6 months leave of absence and is spending the summer in California. BETTY KELLETT NADEAU is taking care of the microscopic work during her absence.

JAMES I. DANIELS, Kansas district geologist with the Continental Oil Company, Ponca City, Oklahoma, has resigned his position and will head the geological department of Slick, Pryor and Lockhart of Wichita, Kansas, after July 1.

CLARE J. STAFFORD, Kansas district geologist with the Darby Petroleum Corporation, has resigned his position and is now in business for himself.

The Kansas Geological Society held its June meeting at the Allis Hotel, June 17. A. C. FRITCHIE of the Baroid Sales Company spoke on "Properties of Drilling Muds and Their Relation to Sample Cuttings."

The department of geology and geography of Northwestern University was addressed during the past academic year by G. H. ANDERSON, California Institute of Technology, speaking on "Migmatites of the Inyo Range"; G. H. CADY, Illinois Geological Survey, "The Classification of Coal"; J. L. GILLSON, The duPont de Nemours Company, "The Monazite Deposits of Travancore"; Professor W. H. HOWARD, University of Illinois, "Petroleum in Limestone Reservoirs"; M. S. KRISHNAN, Geological Survey of India, "The Geology of India"; J. E. LAMAR, Illinois Geological Survey, "Aspects

of the Non-Metallic Deposits"; G. F. LOUGHLIN, United States Geological Survey, "The Physiography of the Front Range"; L. L. MCCABE, Illinois Geological Survey, "Phases of Coal Research." In addition there have been two series of exchange lectures. ERWIN RAISZ, of the Institute for Geographic Exploration, Harvard University, gave five lectures on "Geographic Illustration," while Professor W. H. HAAS of Northwestern University lectured at Harvard University on "The Geography of the Tropics." Professor W. H. BUCHER of the University of Cincinnati gave 5 lectures on "Problems of Geotectonics," while Professor W. E. POWERS of Northwestern University lectured at the University of Cincinnati on "The Geology of the Pleistocene."

CLYDE BECKER, independent geologist, has accepted a position with Wasteka Oil Company.

RUSSELL W. GRIMES, geologist with Shell Petroleum Corporation, Houston, has resigned his position to become an independent operator and consulting geologist.

J. MARSHALL BROWN, for the past 4 years in the production department of the Gulf Oil Corporation in Colombia, has been transferred to the United States and is temporarily located at the Gulf's Drumright office.

GEORGE COATES and RODNEY DELANGE, independent operators and producers of San Antonio, recently left for a trip abroad. They will motor through Europe, inspecting several of the oil fields and will return about October 1.

Humble Oil and Refining Company is moving its offices from San Antonio, Texas, to the Nixon Building, Corpus Christi, July 27. Only C. O. FALK, scout for the company in the Balcones fault zone area, will remain in San Antonio and he will maintain offices at his home, 337 Furr Drive.

The officers, executive committee and members of the Division of Geology and Geography of the National Research Council, for the year beginning July 1, are: chairman, EDSON S. BASTIN; vice-chairman, ROBERT S. PLATT; executive committee, EDSON S. BASTIN, ROBERT S. PLATT, DONALD C. BARTON, FLORENCE BASCOM, F. H. LAHEE, and FRANK E. WILLIAMS; representatives of societies, DONALD C. BARTON and A. F. BUDDINGTON, Geological Society of America; J. F. SCHAIRER, Mineralogical Society of America; CHARLES BUTTS, Paleontological Society; ROBERT S. PLATT and FRANK E. WILLIAMS, Association of American Geographers; JOHN K. WRIGHT, American Geographical Society; THOMAS B. NOLAN, Society of Economic Geologists; F. H. LAHEE, American Association of Petroleum Geologists; members at large, FLORENCE BASCOM, EDSON S. BASTIN, and L. F. THOMAS.

B. J. CRAFT, head of the petroleum engineering department at Louisiana State University, is doing research work for the Gas Power, Incorporated, Houston, Texas.

M. R. CAMPBELL, who has been with the United States Geological Survey from 1889 to 1932, his work covering all of the United States west of the Blue Ridge, is now living at 735 Fourth Avenue, North, St. Petersburg, Florida. CAMPBELL will be 78 years of age on September 30, 1936. He is an honorary member of the A. A. P. G.

JAMES D. AIMER, geologist with the Arkansas Fuel Oil Company, was recently transferred from Russellville, Arkansas, to Shreveport, Louisiana (Drawer 1734).

ROY L. LAY, geophysicist for The Texas Company, has recently been transferred from Los Angeles to Denver, Colorado (Box 2100).

E. K. CRAIG, geologist with the Shell Oil Company of California, has been transferred to Casper, Wyoming. ALEX CLARK has been placed at Cut Bank for the northern Montana district, LESS CLARK at Billings for southern Montana, and F. E. VAUGHN at Denver for Colorado. These geologists will work under the supervision of E. G. ROBINSON, Shell geologist at Los Angeles in charge of the Rocky Mountain affairs.

J. M. MCMILLAN, JR., of Houston, Texas, geologist with the Adams-Louisiana Company, has opened temporary offices for his company's Wyoming operations in the Townsend Hotel at Casper.

H. KLAUS recently in the geophysical department of the Gulf Research and Development Company, Pittsburgh, Pennsylvania, has resigned to go into consulting work. His office address is 402 Broadway Tower, Enid, Oklahoma.

DAVID DONOGHUE, consulting geologist, Fort Worth, Texas, is the author of an article, "Coronado, Onate, and Quivira," which was published in *Mid-America*, Vol. 18, New Series, Vol. 7, No. 2, and reprinted in *Preliminary Studies* of the Texas Catholic Historical Society, St. Edward's University, Austin.

ROBERT BROOKS WHITEHEAD, chief geologist for the Atlantic Oil Producing Company since 1919, long a resident of Dallas, Texas, and prominent in the geological profession and affairs of the Association, died at Detroit, July 1. Burial was at his birthplace, Mount Pleasant, Michigan.

CHESTER W. WASHBURNE, after a year of field work in West Texas, Wyoming, and New Brunswick, has returned to his office, 149 Broadway, New York.

The Kansas Geological Society will hold its tenth annual field conference September 4–7, inclusive. The conference will start at Kansas City, Missouri, and make a detailed study of the Pennsylvanian and Permian rocks between the base of the Missouri series and the Big Blue series. This includes the Lansing and Kansas City groups and the Oread, Topeka, Howard, Cottonwood, and Fort Riley limestones. RAYMOND C. MOORE will be director of the conference assisted by FRANK C. GREENE, NORMAN D. NEWELL, and M. K. ELIAS. For detailed information address Field Conference Committee, 412 Union National Bank Building, Wichita, Kansas.

DESAIX B. MYERS, chief geologist of the Union Oil Company, Los Angeles, California, has been made manager of exploration. EARL B. NOBLE, assistant chief geologist, has been recently appointed assistant manager of exploration.

KESSACK D. WHITE, petroleum geologist, has changed his London address to 68, Pall Mall, S. W. 1.

E. A. RITTER is now area general manager for the Cia. Mexicana de Petroleo "El Aguila," S. A., with headquarters at Avenida Juarez 92–94, Apartado Postal 113-Bis, Mexico City, D. F.

At the Centenary of the founding of the First Geological Survey of Pennsylvania, celebrated at Harrisburg, June 12 and 13, more than 100 representatives of universities, scientific associations, and domestic and foreign surveys were welcomed by Governor EARLE, Secretary of Internal Affairs THOMAS A. LOGUE, and State geologist GEORGE H. ASHLEY. W. C. MENDENHALL responded for the United States Geological Survey, M. M. LEIGHTON for the Association of State Geologists, and FREDERIC WATSON for foreign geological surveys. The A. A. P. G. delegate was J. G. MONTGOMERY, JR., of Oil City, Pennsylvania, Appalachian District representative. The following papers were presented: "Philadelphia, the Cradle of American Science," by F. LYNWOOD GARRISON; "The Geological Surveys, 1836–1936," by RALPH W. STONE; and "The Romance of Geology and the Part Played by Pennsylvania," by GEORGE H. ASHLEY.

THOMAS C. WILSON has changed his address from 940 Western Avenue, Pittsburgh, Pennsylvania, to Commonwealth Gas Corporation, 401 Union Building, Charleston, West Virginia.

FRANK A. HERALD, formerly consulting geologist, Fort Worth, Texas, has been appointed petroleum valuation engineer for the Securities and Exchange Commission of Washington, D. C., effective July 1. He is connected with the newly organized oil and gas unit. His office is 621 Wright Building, Tulsa, Oklahoma.

At the Third World Power Conference which meets at Washington, September 7–12, several papers on the general subject, "Production and Distribution of Petroleum and Its Products," will be presented. MYRON S. WATKINS of New York University will speak on the organization of petroleum industries; E. DEGOLYER of Felmont Corporation, Houston, the status of petroleum production; J. NOEL ROBINSON, Tide Water Oil Company, New York, the history and status of petroleum refining; R. E. HARDWICKE of Fort Worth, production control; and JOSEPH E. POGUE the economic structure of the petroleum industries. Conservation of petroleum and natural gas is to be considered in a paper to be presented by a representative of the United States Bureau of Mines.

ROBERT C. LAFFERTY is in the employ of Owens-Libbey-Owens Gas Department, Box 1375, Charleston, West Virginia.

HERMAN A. FONVILLE is with Geophysical Service Incorporated, Dallas, Texas, with offices at 1311 Republic National Bank Building.

W. A. CLARK, JR., is now associated with the Turman Oil Company, a subsidiary of Middle States Petroleum Corporation, as divisional geologist in the Houston division.

PAUL E. FITZGERALD, of Dowell Incorporated, is situated at the general office of the company, Kennedy Building, Tulsa, Oklahoma.

R. A. STEINMAYER, of the department of geology of Tulane University, and president of the New Orleans chapter of the Reserve Officers Association of the United States, holds the rank and grade of Major, Separate Battalion 457, Engineers Reserve, United States Army.

R. F. MCMILLAN is in the geological department of the Turman Oil Company, Tulsa, Oklahoma.

BEN E. LINDSLY, formerly with the United States Bureau of Mines and more recently in the Division of Conservation of the Department of the Interior, is now petroleum valuation engineer with the Securities and Exchange Commission, Washington, D. C.

CHARLES MERTON REED and BENJAMIN T. SIMONS, who received their master of science degrees at the University of Rochester this year, are employed by the Western Geophysical Company, Tulsa.

ROBERT S. BREITENSTEIN has changed his address from Salta, Argentina, to Texas Petroleum Company, Apartado 877, Bogotá, Colombia.

KIRTLEY F. MATHER, professor of geology at Harvard University, addressed the graduates at the one hundred and fifteenth commencement exercises of Colby College.

DALE SCRUGGS recently of the Continental Oil Company's geological department, has accepted a position with Trinity Oil Company, Wichita.

EDMONDSON D. LUMAN has been made chief geologist for the Atlantic Oil Producing Company, Dallas, Texas, succeeding the late R. B. WHITEHEAD.

LAURENCE VANDER LECK was recently re-elected chairman of the central committee of California Oil Producers and at the same time LAURENCE C. KELLY and H. F. OWEN were renamed vice-chairman and second vice-chairman, respectively, for the fiscal year beginning July 1.

HENRY HINDS, consulting geologist, returned recently from Eastern Venezuela. Last winter he made a short trip to Morocco and Algeria. He is now located at 570 Lexington Avenue, Room 3400, New York, New York.

ED SHAKELY is now in charge of the Shell Petroleum Corporation's land office at Great Bend, Kansas, covering the western part of the state.

W. A. WILLIAMS has moved from Houston, Texas, and is now located in the Clay-Jones Apartments, No. 1802, 1250 Jones Street, San Francisco, California.

W. D. HENDERSON has changed his address from Shawnee, Oklahoma, to Stanolind Oil and Gas Company, Box 2061, Pampa, Texas.

J. E. GUNN left for Arabia, August 7, but his mailing address will be Box 2038, Pittsburgh, Pennsylvania.

HOMER CHARLES, formerly with the Indian Territory Illuminating Oil Company in Bartlesville, Oklahoma, has accepted a position with the Phillips

Petroleum Company as geologist in charge of the Kansas division. He succeeds D. B. WINES who is now with the Tide Water Oil Company in Tulsa.

MALCOLM E. WILSON, vice-president and director of the Lion Oil Refining Company of El Dorado, Arkansas, since 1929, has resigned to accept a similar position with the General American Oil Company of Texas, Shreveport, Louisiana.

C. R. BICKEL, district superintendent for Shell Petroleum Corporation, has been transferred from McPherson to Great Bend, Kansas, to take charge of a new office the company is opening.

HAROLD E. BOYD is with the Coast Exploration Company, Room 733, Federal Reserve Bank Building, San Francisco, California.

CHESTER K. WENTWORTH has written a paper entitled "Geomorphic Divisions of the Island of Hawaii," published as *University of Hawaii Occasional Paper No. 29, University of Hawaii Bulletin*, Vol. 15, No. 8 (June, 1936), 15 pp., 1 fig., 1 table.

PAUL D. TORREY, geologist, has been named as the Texas representative for the Sloan and Zook Company and has established headquarters in Houston, Texas. His home address is 4313 Rossmoyne Avenue.

ALFRED R. EYSSELL, formerly general manager of the Plateau Oil and Gas Company, San Antonio, Texas, has resigned from that position to become associated with Louisiana Land and Exploration Company. THORNTON DAVIS replaces him as vice-president and general manager.

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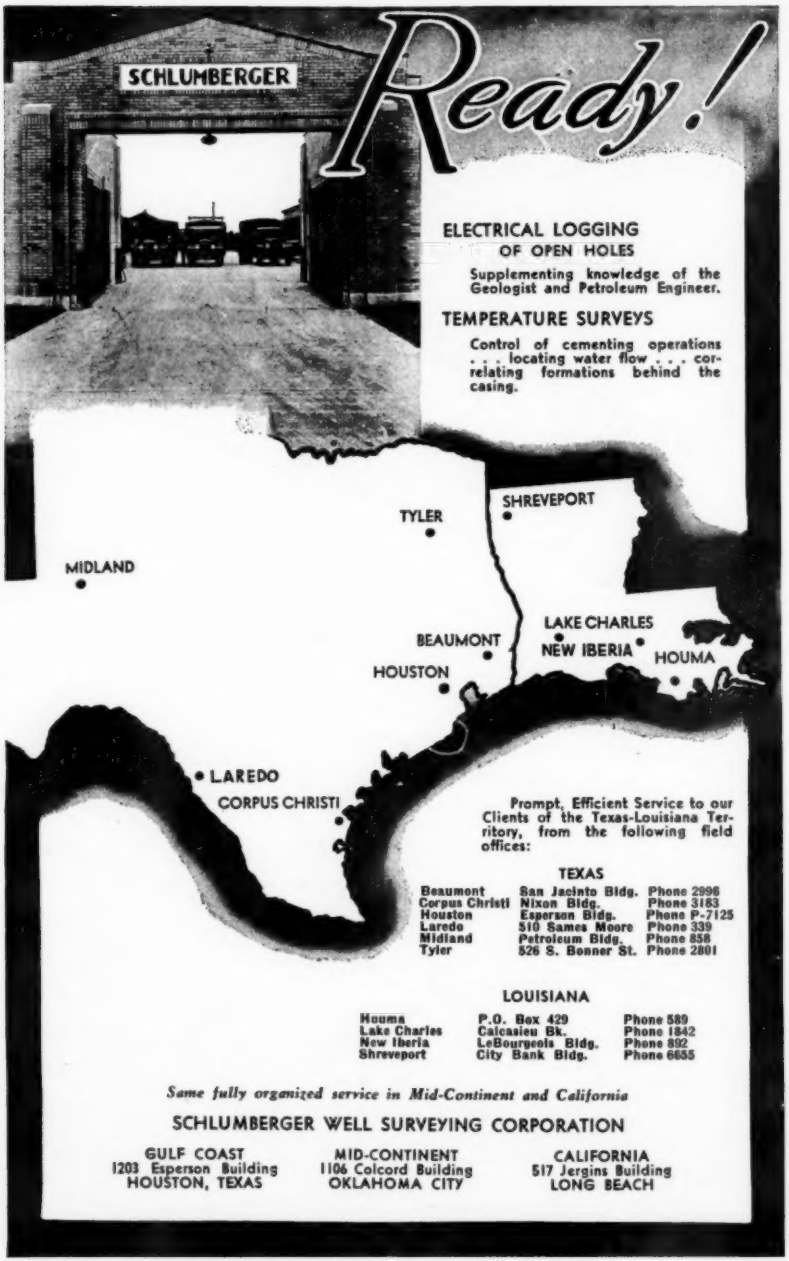
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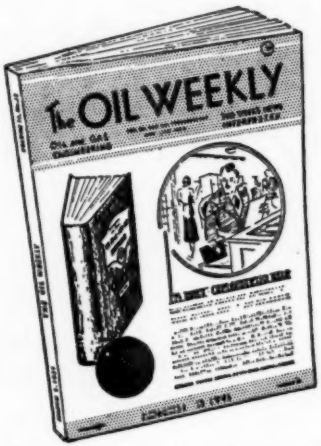

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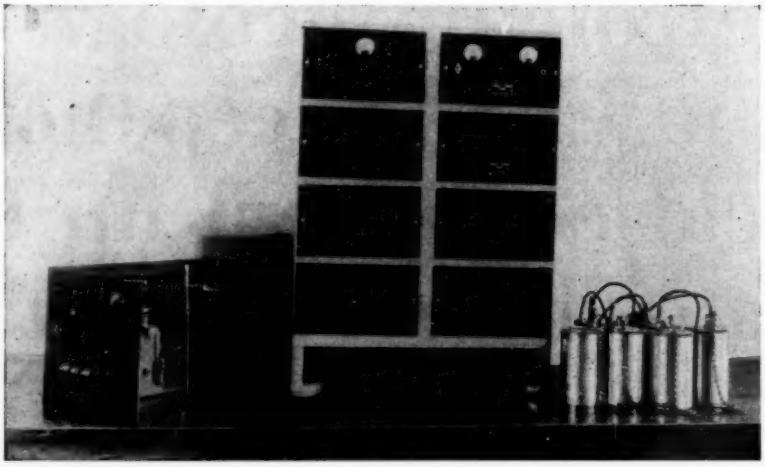

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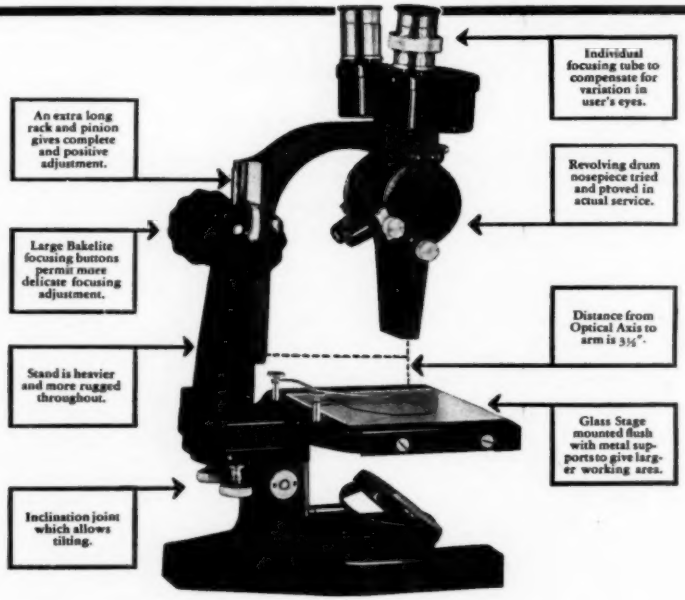
B&L WIDE FIELD BINOCULAR MICROSCOPE


Individual focusing tube to compensate for variation in user's eyes.
An extra long rack and pinion gives complete and positive adjustment.
Revolving drum nosepiece tried and proved in actual service.
Large Bakelite focusing buttons permit more delicate focusing adjustment.
Distance from Optical Axis to arm is 3¼".
Stand is heavier and more rugged throughout.
Glass Stage mounted flush with metal supports to give larger working area.
Inclination joint which allows tilting.

The new B & L Wide Field Binocular Microscope retains all the desirable features of the previous model—the exceptionally wide field, the pronouncedly three dimensional view—and the erect and unreversed image. In addition, this new model has been made larger and sturdier throughout. The moderate price places it within easy reach of serious workers. This new series of B & L Binocular Microscopes is described in a special folder. Write for your copy to Bausch & Lomb Optical Co., 610 St. Paul Street, Rochester, N.Y.

Bausch & Lomb

Bausch & Lomb Optical Co.
610 St. Paul St., Rochester, N.Y.

Please send me complete details on the new Model Wide Field Binocular Microscope.

Name .....

Address .....

WE MAKE OUR OWN GLASS TO INSURE STANDARDIZED PRODUCTION

FOR YOUR GLASSES, INSIST ON B & L ORTHOGON LENSES AND B & L FRAMES

Reflection Seismic Surveys

Successfully Conducted in

MIDCONTINENT—Texas, Oklahoma, Kansas
GULF COAST—Texas, Louisiana, Alabama
PACIFIC COAST—California
ROCKY MOUNTAIN—Colorado, Wyoming, Montana
APPALACHIAN—Pennsylvania, New York
GREAT LAKES—Michigan
CANADA—Alberta, Saskatchewan, Quebec
MEXICO—Tampico Area, Isthmus of Tehuantepec
VENEZUELA

GEOPHYSICAL SERVICE
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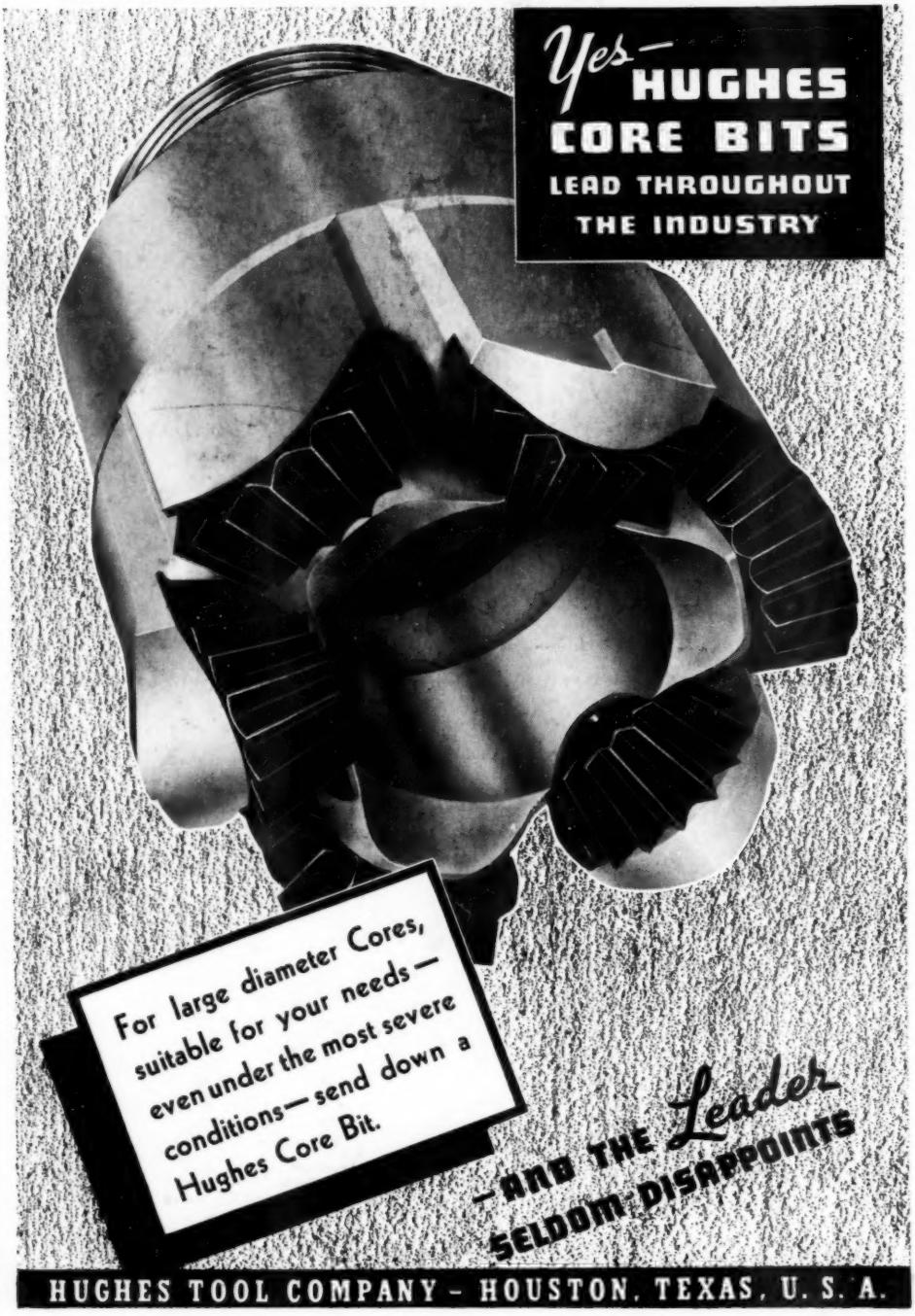
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